

Digital Innovation Through Cybersecurity Learning Factories

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Abstract: Globally, the cybersecurity workforce changes tremendous challenges. Shortages in specialised cybersecurity staff members essentially puts organisations at risk. New graduates can face difficulties in entering the cybersecurity domain due to a lack of experience and knowledge. However, with the advent of newer techniques for knowledge development, we find that learning factories offer a fresh perspective. Learning factories provide a mechanism to remove the barriers in the field of cybersecurity and cultivate a nurturing training environment. This paper looks at the modernisation of traditional training by covering the application of learning factories in the cybersecurity field. It aims to show how knowledge can be geared into more practical schemes to empower participants and expose them to critical cybersecurity skills. Through the paper, it will be demonstrated that learning factories can be used for real-world learning and information sharing. Learning factories embody the principles of knowledge sharing and promotes more efficient knowledge management. With the use of nominated tools and technologies cyber security learning factories can help measure the effectiveness of worker training as well provide for consistent facilitated training. Overall, learning factories can help to transform training and build knowledge application. Learning factories may be set up to tackle real industry challenges and are particularly useful in the field of cybersecurity. Using learning factories there is an opportunity to advance multi-dimensional cybersecurity skills and develop innovation in the field. Due to the added advantages of Information and Communication Technology (ICT) being virtually accessible, there is the added benefits of agility, responsiveness and increased engagement. Using a variety of modes, cybersecurity learning factories can combine the techniques of gamification, videos, multi-media and simulation. All of this provided an augmented and enriched experience for participants. Learning factories are a low-cost solution to replicating working environments thus assisting in skills development. Through the application of learning factories, a skilled workforce can be developed and cultivated.

Keywords: Learning factory, Experiential learning, Cybersecurity

1. Introduction

Staff shortages can be felt across the spectrum in cybersecurity. There is an urgent need to train and nurture new graduates who possess the minimum qualifications and aptitudes required in the cybersecurity profession (Angafor, Yevseyeva, & He, 2020.) In its 2022 Cybersecurity Workforce Study, (ISC)² found that 3.4 million more skilled cybersecurity professionals are currently needed globally (ISC2, 2022). Without suitable staff to support systems and organisations, the risk factor can increase. Misconfigured systems can remain undetected, patching times can be slow, risk assessments can be rushed and omissions on policies may creep in. Skilled professionals are needed to deal with arising issues like data breaches or a ransomware attack. Together with technologies and processes, people-centred solutions are also needed to handle cybersecurity issues.

When graduates emerge out of tertiary educational institutions, they may be keen to enter the workforce. However, practical technical knowledge and expertise in the domain of cybersecurity may be lacking. Learning factories are proposed as a means of bridging the gap between scholastic concepts and technical knowledge. A learning factory is a simulated working environment where individuals can practice applying concepts, tools, and cognitive skills to solve real-world problems (Veerasamy et al. 2023). This type of training is intended to prepare individuals for actual workplace situations by providing hands-on experience in a controlled setting. Learning factories have been a topic of great interest in the last couple of years and using learning factories can be highly beneficial to train employees (Merz, Hoch & Drexel, 2020).

To explore the potential that learning factories offer, the purpose of this is to look at :

- The general cybersecurity skills shortage
- Usefulness of Learning Factories
- Use of ICT in Learning Factories

The research methodology followed entailed a brief literature scan of the field to understand how learning factories emerged from the manufacturing cluster. This is mainly covered in the Overview section of the paper as well as the section looking at the Usefulness of Learning Factories. The authors have also run learning factories training sessions. Based on the experiences of practical learning factory training sessions, the authors have compiled the section on ICT use in Learning Factories and their innovative contributions to the digital space. The

results found in the ICT section are based on observations and practical application of running learning factory training sessions.

2. Overview

The term learning factory was first coined and patented in 1994 when the National Science Foundation (NSF) in the US awarded a consortium led by Penn State University a grant to develop a “learning factory (Abele et. al., 2017). It referred to interdisciplinary hands-on senior engineering design projects with strong links and interactions with the industry. Over the years, learning factories have predominantly been applied to the manufacturing sector due to the strong challenges in training and correlating competency requirements. Another challenge was the adaptation and enhancements to their education concepts and methods.

In order to succeed within the fourth industrial revolution, companies of the producing sector have to prepare their employees for these competences (Prinz, Morlock, Freith, Breikopf, Kreimeier & Kuhlenkötter 2016). The key feature of the fourth industrial revolution is digitalisation and therefore technological modernisation. Critical to these concerns is how to handle the vast volumes of data and information as well as the incorporation of new methods and technologies for work in Industry 4.0.

Society has grown increasingly dependent on technology which makes cybersecurity an even greater priority. The pace and breadth of technological progress are increasing at a surprising rate (Roodt & Koen 2020). For sustainable growth, it is critical that cybersecurity becomes a key concern in this growing digitised and connected world. Tapping into the potential of learning factories, workers and job seekers can gain access to practical knowledge that promote innovation and transformation. Attracting good talent and retraining are crucial for growing skills and providing development opportunities.

Figure 1 shows an overview of how learning factories can be applied to cybersecurity. Due to the remote, virtual and hybrid capabilities of ICT, learning factories in the field of cybersecurity can ideally provide a platform to nurture talent. Members can interact with various learning platforms containing simulations, games, videos, exercises, animation, scenarios and applications to learn about the latest technology area and familiarise themselves with the content. Thus, organisations can broaden talent and enable transformative work practices with in-skills training. In addition, by providing the opportunity for further education and skills development, members can grow in experience. Learning factories setups can innovate cyber security skills development due to the digital capabilities and revolutionary delivery methods like virtual reality, gamification, simulation, animations, and the broad spectrum of multimedia. It also enables information sharing and real-world application learning.

The main goals of learning factories are either technological and/or organizational innovation (if used for research), or an effective competency development (if used for education and training), i.e. the development of the participants’ ability (including motivational and emotional aspects) to master complex, unfamiliar situations (Abele, Metternich, Tisch, Chrissolouris, Sihn, ElMaraghy, Hummel & Ranz 2015)

Furthermore, as technological advances transform jobs, people may need to retool their skillsets to better prepare for their roles. Because of the increased complexity of state-of-the art technologies educational institutions need to provide practice- orientated teaching methods in learning factories to help engineers of today understand the impact of those developments (Komenda, Reisinger and Sihn, 2019). Training and upskilling are imperative to remaining current to digital innovations. Learning factories offer the opportunity for members to improve their knowledge base by exposing them to practical training in an interactive environment. Learning factories present a promising environment for education, training and research (Abel et. al., 2017).



Figure 1: Overview of Cybersecurity Learning Factories

Future learning factories are set to drive continuous improvement, innovation and knowledge creation. Human capital development should explore knowledge generation and harnessing experiential learning for growth and development. Furthermore, training should promote independent problem-solving skills amongst workers and the capability to perform across various areas. Training must be supported and endorsed by HR policies. HR policies must incentivise and promote training. Training offerings should aim to be multi-dimensional, diverse and integrate various capabilities. For example, technical skills, interpersonal skills, planning skills can be combined to show wider application areas. For such integrated training to be possible, there must be suitable training facilities. Furthermore, worker participation in the workplace is highly recommended, therefore participation-enhancing training must be offered. The emerging idea is that learning factories are a possible solution to the needs of practical skills training and promote experiential learning.

The Centre for Teaching and Learning explains that experiential learning allows the following processes (2022):

- reflection, critical analysis and synthesis;
- opportunities for students to take initiative, make decisions, and be accountable for the results;
- opportunities for students to engage intellectually, creatively, emotionally, socially, or physically; and
- a designed learning experience that includes the possibility to learn from natural consequences, mistakes, and successes.

Figure 2 shows how the learning factory can be applied to the cycle of learning in that members are able to have direct exposure/concrete experience. Thereafter, after the initial observations, it can be related to previous experience and knowledge. Application of new ideas and skill practice is also facilitated. Eventually, the participant can distil the experience based on the contact with practical and abstract concepts.

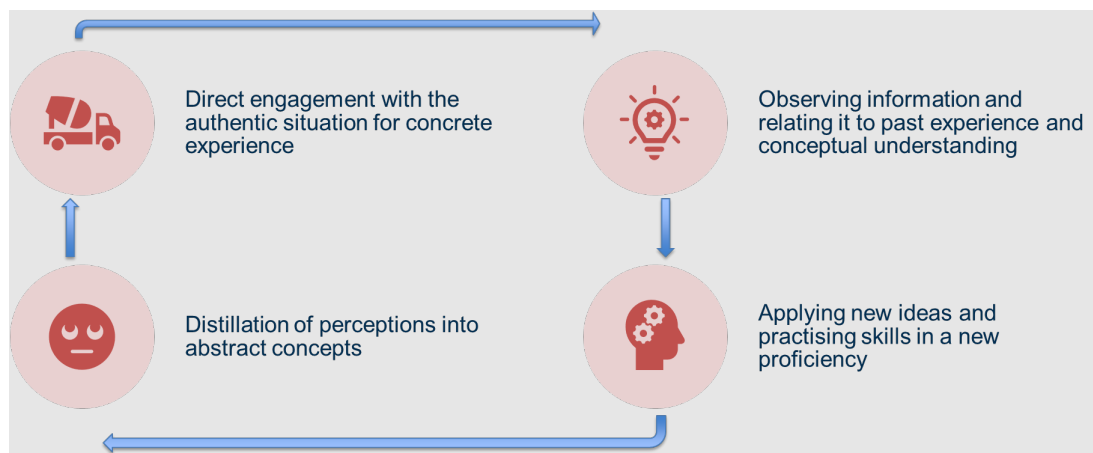


Figure 2: Cycle of Learning

Together with a high degree of knowledge, companies expect their employees to utilise their knowledge and operationalise this knowledge in unimaginable situations (competencies) which shows the requirements for

future and actual employees having to act in real problem situations (Cachay, Wennemer, Abele & Tenberg, 2012). More action- orientated learning approaches are needed.

Traditional learning equips one with the knowledge and principles which may or may not be received and applied by the trainee in the intended manner. However, LF provide an additional layer of learning in the form of “hands-on experiential learning”. Experiential learning goes beyond teaching to training participants through practical and direct engagement with the knowledge being imparted. Other notions like “knowledge factory”, model factory” and “teaching factory” can be used to describe similar kinds of learning systems (Tisch, Hertle, Abele, Metternich & Tenberg, 2014).

Learning factories provide experiential learning by simulating a real work environment to trainees. Simulation as an immersive teaching and learning method has proved to be effective in captivating, engaging and intriguing participants as they learn. This is due to participants being able to implement the imparted knowledge and seeing its effects in real time and environment. The LF’s setup and tools, the simulated conditions may be tweaked to represent real workplace challenges, while the participants apply the imparted knowledge in their unique way to solve these realistic challenges.

Learning Factories pursue an action-oriented approach with participants acquiring competencies through structured self-learning processes in a production-technological learning environment (Tisch, Hertle, Cachay, Abele, Metternich, & Tenberg, 2013). Thus, users can be taught necessary competencies in a practical manner that promotes knowledge growth, experiential interactions, and actionable engagement.

3. Usefulness of Learning Factories in the Workplace

According to research from LinkedIn, staff within the technology sector have the highest turnover of over 13% (Lewis, 2023). The constant entering and exiting organisations is costly as organisations need to re-train employees. Furthermore, due to technological changes, employees need constant training. Integrating learning factories into the workplace could assist in upskilling employees continuously.

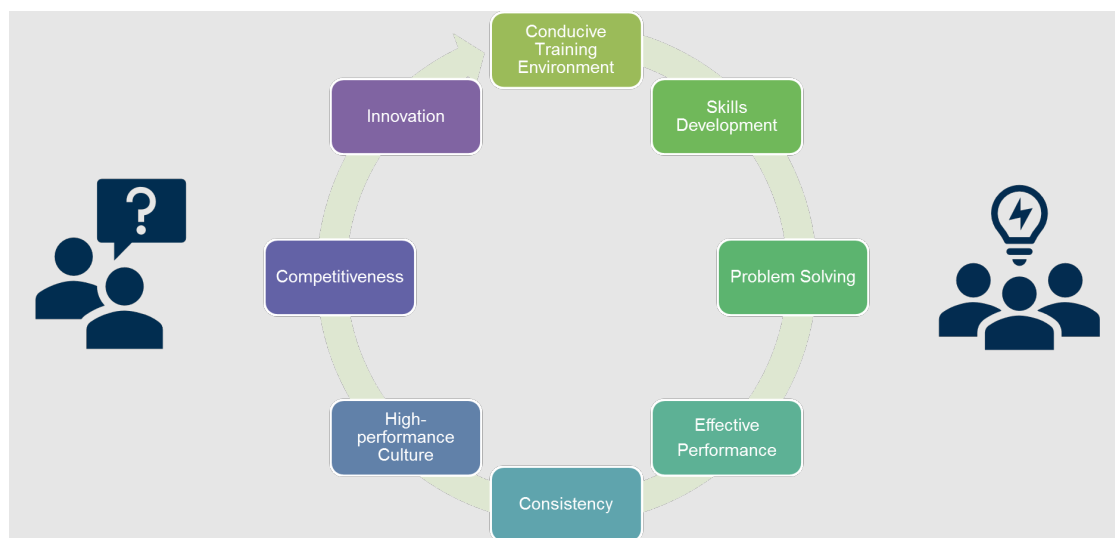


Figure 3: Usefulness of Learning Factories

Figure 3 shows the usefulness of learning factories in the workplace. These include:

- Conducive training environment – training platform/ classroom contains relevant material to expose participants to concepts. Learning factories also offer a high potential for blended learning setups, where the learning factory serves as a meeting place and application scenario (Tisch, Hertle, Abele, Metternich & Tenberg, 2016).
- Skills development – practical exercises promote skills development and knowledge growth. The key to competency development is the ability to master knowledge, this comprises cognition and comprehension of knowledge (Cachay, Wennemer, Abele & Tenberg, 2012).
- Problem solving – application of knowledge and skills for problem solving. Learning Factories can have different learning modules, formal and informal learning processes during learner situations in which participants master unknown problem situations (Enke, Mladineo & Monetti 2016)

- Effective performance – exposure and practical training can help improve performance. In line with the human capital perspective, raising the skills of the labour force is seen as important in contributing to the spread of “high-skill” work practices and thus enabling higher productivity growth (Barton & Delbridge, 2001).
- Consistency- best practices can be shown, thus resulting in more uniform responses.
- High-performance culture – support and reskilling encourage culture of high performance.
- Competitiveness- improved skills provides organisation with edge over competitors. In addition, members may enjoy the benefits of friendly competition to achieve and strive for better results in training exercises, quizzes and other measured activities.
- Innovation- use of progressive techniques encompassing digitised technologies can provide more forward-looking solutions. This also helps transform training. Especially, innovative learning environments must be able to react training mentioned challenges in an interdisciplinary manner (Abele et. al., 2017).

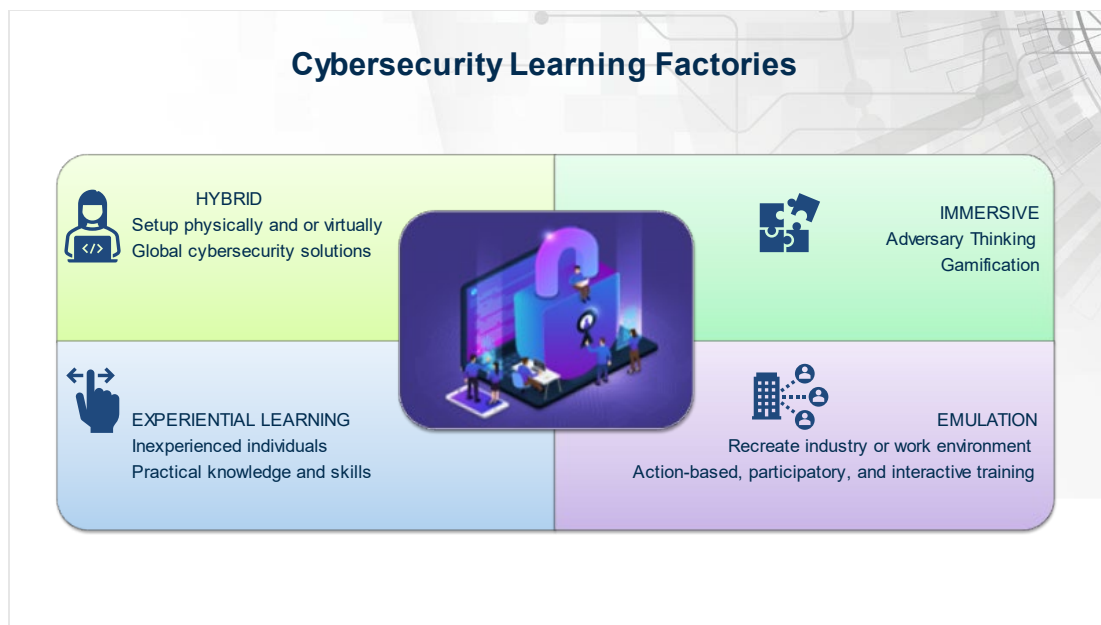


Figure 4: Cybersecurity Learning Factories Features

For cybersecurity learning factories, some key characteristics are captured in Figure 4. Due to the remote options in the ICT field, cybersecurity learning factories can be set up in a laboratory environment as well as online. Many training aspects can be on-line, or software/application based and thus participants can gain access from many locations. In person participation in a learning factory is also an option. Thus, hybrid options are available for cybersecurity learning factories.

Part of the offering of a cybersecurity learning factory will be an immersive experience. Adversary thinking is an essential skill for cybersecurity experts, enabling them to understand cyber-attacks and set up effective defenses (Švábenský, Vykopal, Cermak & Laštovička, 2018). When it comes to specific offensive and defensive practices related to the cybersecurity field, there are options for adversarial thinking. Particularly when looking at areas like penetrations testing and threat hunting, the goal is to walk in the shoes of an opponent and consider invasive activities. In various other aspects like risk evaluations and vulnerability assessments, adversarial thinking is also key to identify stronger controls.

Learning factories can provide an emulation of the work environment. For example, intrusion detection tools can be forming part of the training. The actual tool usages and use cases can be worked through. This provides for action-based participation and interactive training whereby users gain hands on experience with real world experience. Learning factories provide a suitable forum for knowledge generation in that the everyday platforms can form part of the training and help users gain valuable experience.

A key characteristic of learning factories is that it offers a useful stage for experiential learning. New graduates or workers may lack experience in certain areas. However, with learning factories they can interact with a variety of training mediums that provide for practical knowledge and skills development. The next section will look at

the use of ICT in cybersecurity learning factories and how users can benefit from a wide variety of training material.

4. ICT in Learning Factories

Tisch and Metternich (2017) outline challenges for a LF: i) they are resource intensive in space, equipment and personnel, ii) appropriate selection of a research/teaching topic, iii) limited scalability, and iv) unknown effectiveness.

Since the advent of the third and fourth industrial revolutions in addition to the recent global pandemic Covid19, the world has been gradually innovating from traditional methods of productivity to emerging ones that leverage on the power of digital ICTs. As a result, productivity can be achieved at a rapid pace and at low costs. A cybersecurity learning factory is an instance of such, as it promotes cybersecurity education by leveraging on interconnected ICTs, emerging technologies and the internet. As a result, knowledge is widely accessible and sharing simplified. Emerging innovative teaching methodologies include the use of gamification, virtual or hybrid collaborative platforms, animation and simulation techniques to influence learning behaviours. Since ICT has flexible communication and scalable features cyber security learning factories can overcome many of the challenges found by Tisch and Metternich (2017). Topic selection can be provided based on different modules and users performance can be measured which can show improved effectiveness. Based on a Cybersecurity Learning Factory Contextual Attribute Model proposed by Veerasamy et al. (2023) all the above-mentioned inexhaustive teaching techniques may be incorporated (see Figure 5).



Attributes	Qualities
Function	training, skills development, competencies, research
Mode	strategic, operational, exchange
Benefits	cooperation, collaboration, transformation, skilled workforce
Methodology	agile, adaptive, active, responsive, engaging
Features	virtual access, hybrid solution, extendible

Figure 5: Contextual Attributes of Learning Factories (Veerasamy et al, 2023)

Figure 5 presents the attributes and relative qualities of a cybersecurity learning factory:

- Function describes the purpose of a learning factory;
- Mode describes the objectives of a learning factory;
- Benefits are the advantages of a learning factory;
- Methodology describes the teaching and learning techniques of a learning factory; and
- Features describe the setup of a learning factory.

It is mainly the Features and Methodology that highlight the use of ICT in a cybersecurity learning factory.

Gamification entails implementing the creative techniques that are used in gaming when teaching, to promote intriguing challenges, engagement, the will to proceed, and rewards in the learning process. As such, gamification in a learning factory would creatively integrate video, audio, animation, quizzes, simulation, puzzle-based challenges, rewards, etc, into game-based lessons and application tasks to facilitate in-depth learning (Raisi et al., 2021). Employing gamification in the learning process transforms it from a monotonous and laborious process into an engaging and dynamic experience. Learning becomes entertaining, collaborative and competitive, helping to foster a deeper understanding of the subject matter (Raisi et al., 2021). Interactive training sessions, including educational games, are expected to have the highest learning effect among the applied learning methods because of providing opportunities for exploration, experimentation and problem solving (Ratan & Ritterfield 2009) Emerging technologies such as machine learning can be incorporated in game-based learning factories to increase interactivity between user and platform, thus further improving the quality of learning and teaching. In a cybersecurity learning factory, machine learning technology can be used to provide real-time and customised feedback to the user by detecting wrong inputs such as a syntax error in a programming language, interpreting that, and providing the most likely set of inputs a user may choose from to

correct their input (Loftus & Narman, 2023). Personalised feedback has been proven to enhance learning, therefore, incorporating machine learning in a cybersecurity learning factory can ease the complexity of cybersecurity training according to individuals' varying capabilities (Loftus & Narman, 2023)

Simulation technology involves the use of computer software to replicate real-world scenarios and processes in a virtual environment. In the context of learning factories, simulation has emerged as an effective tool for providing participants with a safe and controlled environment to experiment with various manufacturing processes. Simulation-based learning enables participants to gain hands-on experience in a virtual setting and obtain immediate feedback on their performance. This feedback mechanism can help participants identify errors and gaps in their knowledge and provide an opportunity for participants to correct and improve their performance in a timely manner. As a result, simulation-based learning has become an increasingly popular approach for enhancing learning outcomes and skills development in learning factories.

Virtual reality is an emerging technology that leverages software tools to create a computer-generated environment that replicates real-world scenarios. Within the context of learning factories, digital and virtual learning factories have emerged as a means of creating an online learning environment that is accessible from anywhere. In such environments, participants can engage in simulation-based activities, such as layout planning and concurrent engineering, which provide a realistic representation of manufacturing processes in a virtual space (Tvenge et al., 2020). This approach enables participants to experiment with different scenarios and gain valuable hands-on experience, without the constraints of physical space or equipment.

Through virtual reality, participants can receive real-time feedback on their performance, enabling them to identify and correct errors quickly. The virtual environment also allows for the creation of multiple scenarios to test various skills, thereby facilitating a deeper understanding of the subject matter. Additionally, virtual reality-based learning can increase participant engagement and motivation, as participants are immersed in an interactive, gamified experience that fosters a sense of competition and achievement.

The use of dynamic and interactive ICT platforms provides for a richer experience and helps grow the knowledge base of the participants. Due to the innovation offered by digitalisation, users can have a much more personalised and intensive experience and help with knowledge retentions and skills development.

Various software training platforms provide for automatic quizzes, practical's, exercises, videos, badges and rewards. With the use of these animated and interactive offerings, participants are encouraged to achieve certain goals. Such platforms can also offer background training content. In this way, the knowledge required for job related tasks can be encapsulated into smaller modules which makes them more digestible to the users.

5. Conclusion

The innovation in learning factories promotes better knowledge generation, transfer and application. ICT evolves at a rapid pace. So too does cybersecurity. New threats and threat actors emerge continuously. Through cybersecurity learning factories, underlying theory as well as emergent knowledge can be conveyed.

This paper elaborates on the benefits of learning factories which can contribute extensively to knowledge management. The innovation offered by learning factories provides a more practical method for participants to distill knowledge from abstract concepts by offering practical training and exposure to tools and technologies. ICT provides for several digitized offerings that can further support the learning factory objectives. Through hybrid, virtual, gamification and simulation techniques, cybersecurity learning factories offer tremendous potential to help with skills development and knowledge generation.

Future work on this topic will include exploring learning factories within the cyber security domain towards replication to improve the cyber security posture of organisations within the country,

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