Towards the Usefulness of Learning Factories in the Cybersecurity Domain

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Abstract: The success of an organisation depends on its employees' skills and the extent to which they are developed. Although organisations often assume employees are fit and ready for a new position or new developments in their functions, employees need adequate training before, during and after effective performance in their respective roles. Amongst other important roles, training is significant in problem-solving, continuously improving skills, and creating consistency or culture in the work environment. Nonetheless, the significance of training is often disregarded or not understood by organisations as there are often inadequacies, inconsistencies, and ignorance from the employer. Furthermore, organisations are facing cybersecurity skills shortages. Some specialists leave the profession due to a lack of skills or support. The lack of experienced and qualified cyber security specialists increases the risk of IT system systems being targeted with cyber-attacks. Having insufficient cybersecurity staff, companies may struggle to protect their networks from attacks. Organisations are being placed into a troubling position as the threat landscape continues to evolve. With the growth in volume and sophistication of cyber security attacks, the problem of a skilled workforce is exasperated. In order to support the cybersecurity workforce, this paper proposes the implementation of learning factories. Typically, learning factories have been used in the manufacturing sector. However, the fundamental principles and guiding ideologies can also be applied in the cybersecurity domain. Learning factories provide a mechanism to remove the barriers of entering the field of cybersecurity by cultivating and nurturing a cybersecurity workforce. They enable the broadening of the scope for talent and change our current working practices and tighten the gap between education and experience. The closing of the talent gap is an important imperative for cybersecurity. In this paper, a motivation and description of the functionality of learning factories for cybersecurity is provided. Through this paper the benefits of learning factories will be highlighted in order to show the advantages of active engagements in learning activities, real-world application and information sharing.

Keywords: Cybersecurity, Information Security, Learning factory, Experiential Learning, and Cybersecurity skills

1. Introduction

Research has demonstrated that there is a cybersecurity skills shortage globally. The Joburg Centre for Software Engineering (JCSE) annual surveys have reported an acute shortage of skilled information and communications technology (ICT) workers in South Africa, with information security a leading issue for employers (Schofield, 2016). Tertiary education institutions do not possess the necessary responsiveness. According to Pew Research Centre, mobile access penetration in South Africa as of 2018 was 95% (Pew, 2019); only 5% of adults do not have access to a cell phone. Due to the lack of cyber security skills, this has opened society to vulnerabilities and a marked increase in cybercrime. To deal with this shortage of skilled information security personnel, South Africa needs to develop a new pool of youth with cybersecurity skills.

The lack of cybersecurity skills is not an easy problem to solve. Typically, students need to enrol at a tertiary level institute, complete a degree or diploma, and thereafter supplement this with certifications. This process can take a few years in which organisations still actively look for skilled specialists,. To assist with this, the researchers investigate learning factories in the cybersecurity domain. There are various cybersecurity training and course offerings, but there is a disconnect between such training and the end-goal of developing skilled information security personnel. Most of the learning factories exist in the manufacturing domain, and there are a few cases of using learning factories for advancing manufacturing with the fourth industrial revolution (Baena et. al, 2017, Elbestawi et. al, 2018, Faller and Feldmüller,2015).

Integrating such training and course offerings into a learning factory can assist with the problem at hand. The research objective that this work intends is to investigate attributes for a cybersecurity learning factory. This will feed into a bigger objective, i.e., whether a cybersecurity learning factory can deal with the shortage of skilled information security personnel.

Learning factories can provides a useful mechanism to up-skill and train cyber security specialists. Due to the global cybersecurity shortage, it is imperative to propose innovative methods to empower and maintain cyber security skills. This paper will provide insight into how learning factories can be applied, as well as their benefits.

The structure of the paper is as follows: Section 2 provides a description of the usefulness of learning factories by initially looking at the manufacturing sector and then the application of learning factories to cyber security. Section 3 discusses the process of experiential learning in learning factories. Section 4 provides an overview of the contextual attributes of learning factories.

2. Usefulness of Learning Factories

2.1 Manufacturing Sector

Learning factories initially emerged as a teaching and learning concept out of the manufacturing sector, to train workers on how to apply Lean Manufacturing methods, among others. According to Monetti et. al (2022), Lean Manufacturing (LM) methods are typically applied by factory workers in the production line for three main objectives, namely:

- To foster skills to workers;
- To identify and eliminate non-value adding steps and processes in the production line; and
- To continually improve worker and manufacturing performance.

One of the well-known LM methods is the Kanban system. Kanban is a Japanese word meaning ‘signboard’. The Kanban system means using visual cues to prompt the action needed to keep the process flowing. Kanban is a scheduling system developed to improve the efficiency of a manufacturing system. It was developed by a Toyota engineer who observed how retailers stocked their shelves- they would only order supplies as the old stock was dwindling. Therefore, Kanban is also known as just-in-time manufacturing which is to maintain efficiency in industrial production (Powell, 2018). There are several other LM methods such as Value Stream Mapping (VSM), Kanban/Pull production, 5S, and production smoothing” (Monetti et al., 2022). Workers require practical training to appropriately implement the latter tools. Learning factories were originally used to facilitate practical training for factory workers to implement LM in an environment that resembles a real factory assembly line. By definition, a learning factory is an integrative educational environment, designed to promote learning by training individuals to practically apply concepts, tools and cognitive skills to solve problems in an environment that is set up to resemble a real working environment (Enke et al., 2016, Mladineo et al., 2016, Monetti et al., 2022). Learning is often fostered when individuals are given the opportunity to put into practice their skills and not being shown something or taught in the classroom.

The focus of modern learning factories in the manufacturing sector is to advance employees’ skills, agility and trust as demands in the work environment are consistently rising, compelling flexibility and strategy in problem solving across the board (Barton & Delbridge, 2001). The value of a learning factory in modern manufacturing is to upskill vertically, horizontally and across the organisational hierarchical (Tisch et al., 2015). The latter view is derived from developed manufacturers, such as Japan where the Kanban LM method originates, which place human resources, productive and production processes at the center of industrial success (Barton & Delbridge, 2001). Organisations thrive when employees’ skills and development track record is strong. Therefore, learning factories offer practical and complex employee training which is an investment that can improve growth, application areas and competencies according to domains specifics (Tisch et al., 2015). The following paragraphs expand on the latter discussion.

Organisations may assume that employees are skilled and ready for a new position or new requirements in their roles, however employees need suitable training to ensure effective performance (Barton & Delbridge, 2001). Amongst other important roles, training is significant in problem-solving, continuously improving skills, creating consistency or culture in the work environment. However, the value of training is often disregarded or mis-understood by organisations, resulting in inadequacies, inconsistencies, and unawareness from the employers’ side. Some of the inadequacies of training found by researchers are as follows (Barton & Delbridge, 2001):

- The effectiveness of worker training is not measured;
- The nature of training and training is not appropriately considered;
- Training initiation is not standardised; minimal evidence of training following promotions; and
- There is no shared or outlined concept regarding the purpose of training

Production and productivity requirements are changing in the manufacturing Sector. There are greater demands on workers as there is an increasing need for continuous innovation (Barton & Delbridge, 2001). The latter authors conclude that there is a greater need for active worker involvement and a transferral of decision-making roles that were previously reserved for managers to lower position workers. Furthermore, the role of training for supervisors and managers is shifting to be more focused on interpersonal skills development. The challenge however is that there is a lack of appropriate training facilities. Consequently, there is a lack of continuity and consistency in facilitated training which results in workers not having an appreciation of the significance of training (Barton & Delbridge, 2001). A practical example on the suitability of a training facility is that production plants and roles in an automotive factory are different, other workers may require technical skills while others require assembly or administrative skills. Therefore, it is important to design training offerings with envisaged skillset, environment and nature of work in mind.

Learning factories are commendable in resolving the issues discussed above. Learning factories are described as efficient systems in facilitating strategic and complex training processes that can go beyond competency building, to innovation as well (Zancul et al., 2022). Learning factories differ from traditional learning in that they equip individuals with applicable knowledge and principles to practise the lessons that were offered in a correct and intended manner. Learning factories provide an additional layer of learning in the form of "hands-on experiential learning" which trains participants through practical and direct engagement with the knowledge being imparted (Monetti et al., 2022, p. 1). Furthermore, learning factories foster experiential learning through simulation, an immersive teaching and learning method that has proved to be effective in captivating, engaging and intriguing participants as they learn (Monetti et al., 2022). Simulation is effective as participants are able to implement the concepts, tools or equipment provided in the learning factory, and observe its effects in real time and environment (Monetti et al., 2022). Subsequently and in accordance to "Bloom's taxonomy model in the cognitive domain" (Bloom, 1956), not only will the participants understand and remember the imparted knowledge— they will also be able to apply the knowledge appropriately, analyse its efficacy thus evaluating their competency in solving problems, while further improving personal and organisational performance by creating unique and innovative solutions. Learning factories, therefore, are the breeding ground for competency development and innovation.

Importantly, learning factories are not limited to the manufacturing sector, they can be adapted and applied in various sectors and environments that require practical skills (Enke et al., 2016). It has therefore become common practice for academic institutions to set up learning factories, especially for the built environment and engineering courses, in order to tackle real industry challenges (Monetti et al., 2022). The next section discusses the effectiveness of learning factories in fostering cybersecurity skills and competencies.

2.2 Cybersecurity Learning Factories

Learning factories may evolve out a collaboration of various stakeholders like corporate organisations, research institutions, and universities. The aim is to provide strategic guidance through the use of educational tools that help build competence, skills development as well as carry out research and development (R&D) and innovation.

Cybersecurity is conventionally perceived as solely technical, and subsequently tackled from a technical perspective only. However, cybersecurity is as political, social and economic as it is technical in nature. Therefore, to comprehend cybersecurity, a multi-dimensional approach and perspective is required. Researchers (Ramluckan et. al , 2019) note the theoretical acknowledgement of the need for a multi-disciplinary collaboration in cybersecurity research studies, and the offsetting lack of practicality in achieving it. Subsequently, the challenge of inadequate cybersecurity skills and innovation persist. To this extent Ramluckan et al. recommend the following (2019):

- Allowance for multi-dimensional research methodologies in cybersecurity studies;
- An ease in the "rigid educational structure" (i.e., NQF) of South African Higher Education Institutions (HEI); and
- Exclusive cybersecurity courses or qualifications, which are not offered in South African HEI, except as modules in technical or engineering courses, thus excluding social or legal courses for example.

Learning Factories present an imperative opportunity to advance the ideal multi-dimensional cybersecurity skills and innovation in the field. This is due to the nature of the learning factory being collaborative and involving diverse stakeholders, such as government, private or public sectors, industry experts and academic institutions who can offer diverse contributions (Zancul et al., 2022). Furthermore, the flexibility of learning factories to be setup physically and or virtually (Enke et al., 2016) may be advantageous given the physical restrictions resulting from the global Corona Virus pandemic and the persistent digital divide. Therefore, there is a need for conducive cybersecurity learning factories that will facilitate national and international collaborations and sharing of holistic and multi-dimensional skills that are required to potentially solve the global cybersecurity challenges the world is faced with.

2.3 Application Example

"Adversary Thinking" is a commendable skill to possess to participate in or achieve cybersecurity goals. Adversary thinking is the ability of a cybersecurity professional to act like an attacker in order to devise effective defence mechanisms (Švábenský et. al, 2018). Such a skill can be cemented through a hands-on approach, such as interactive educational games to measure and assess student development (Švábenský et. al, 2018). Learning factories, through simulation, enable a secure environment to train individuals for adversary thinking.

The increasing demand for cybersecurity experts in the labour market exceeds the supply as there is a persistent shortage of skilled personnel. Therefore, there is a need for work-readiness programs for undergraduate students in higher learning institutions. To this effect, a hands-on learning environment that realistically simulates threats and attacks in cyberspace may be developed to teach computer networks and information security students practical defense mechanisms (Švábenský et. al, 2018). Adapting cybersecurity education into a game is a well advocated teaching and learning method among other immersive methods. Therefore, practical cybersecurity skills such as penetration testing may be offered in the form of a game in a learning factory, which promotes learner participation and engagement. The use of games in a learning factory supports traditional teaching and learning methods (Švábenský et al., 2018).

The International Academy for Production Engineering outlined the key characteristics of a learning factory (Abele et. al, 2015). We have adapted this to the cybersecurity domain for the application example in Table 1. Characterisation of the cybersecurity domain is the first step towards conceptualisation.

Table 1: Application example mapping to key characteristics of a cybersecurity learning factory (Adapted from Abele et. al, 2015)

Dimension	Feature	Cybersecurity application
Purpose	teaching and/or training and/or research	Teaching and training with skills on penetration testing for infrastructure or web-based application using University students/interns to address the cybersecurity skills shortage in South Africa.
Process	authentic + multi stations + technical and organizational aspects	The process involves using cyber security simulation and training tools hosted on computers.
Setting	changeable + real or virtual value chain	The learning environment will hybrid. To initiate, it will be in-house instructor led and continuation can occur using online tools.
Product	physical or service	No products will be manufactured in this environment. Skills will be developed and challenges will be completed.
Didactics	concept based + formal and informal learning + own actions of trainees + on-site or remote learning	Pre and post assessments will be conducted. The initiation phase will be with the help of an instructor. Thereafter, participants will work on their own and be evaluated.
Operating Model	sustainable plan allows the ongoing operation	This project will be started using government funds and thereafter be supplemented from other initiatives.

3. Experiential Learning through Learning Factories

Before students or new graduates/employees can embark into the real workspace, learning factories could be used to gain practical knowledge and skills. In the cybersecurity field, particularly new employees can benefit from experiential learning to firstly imbibe knowledge and skills before entering the real-world domain. Previously internships, in-service training, student teaching and undergraduate exchange programs have been used for experiential learning. Learning factories also provide a suitable solution for exposure to diverse skillsets.

The Centre for Teaching and Learning considers experiential learning to contain the following elements (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.

Kolbs proposed a cycle of learning in 1984 that also depicts experiential learning (see Figure 1). It entails (Kolb, 1984):

- Direct engagement with the authentic situation for concrete experience;
- Observing the information and relating it to past experience and conceptual understanding;
- Distillation of perceptions into abstract concepts; and
- Applying new ideas and practising skills in a new proficiency

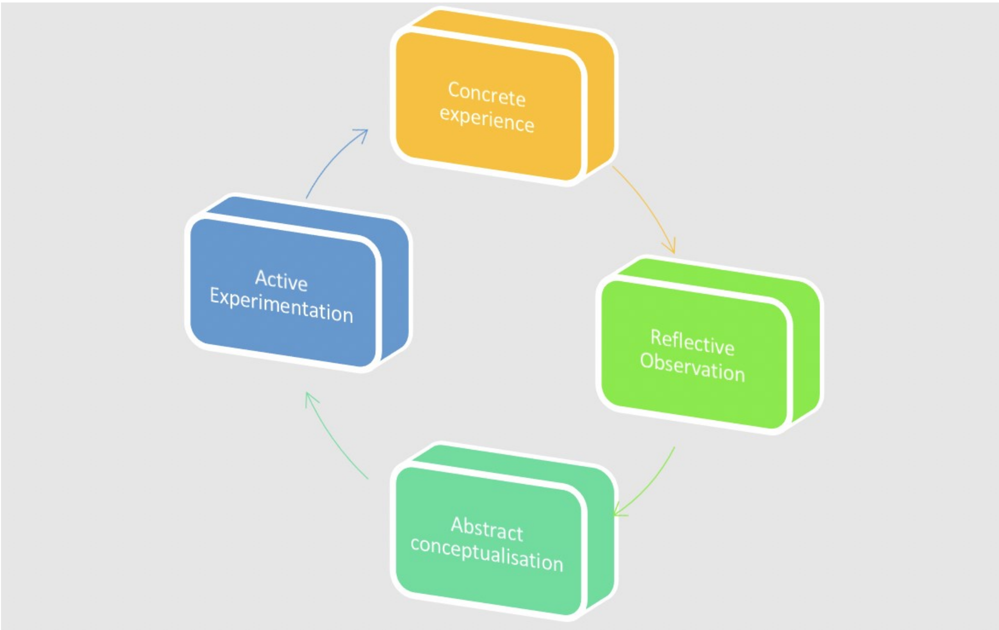

Figure 1: Cycle of Experiential Learning (Kolb, 1984)

Learning factories enable learners to investigate and experiment, be exposed to challenging situations and discover new solutions. It provides an ideal platform for learner to identify connections between concepts as well as apply theory and practical knowledge.

Learning factories serve three purposes (Monetti et. al, 2022). Firstly, recreating a real industrial or work environment either physically or through emulation, in the classroom. By classroom, this study is referring to any learning environment. Secondly, learning factories can recreate the conditions (e.g., setup and time constraints) in the industrial environment, in the classroom. Lastly, learning factory complement traditional teaching and learning processes by providing action-based, participatory, and interactive training. Learning factories support the concept of experiential learning by integrating the core processes of learning with experience offering in a suitable environment.

Conventionally, learners are taught the theoretical concepts of a particular field, however, they are not trained on when and how to implement those principles in the real world. Experiential learning is somehow transferred to the workplace, which results in incompetency. However, learning factories solve that problem in its entirety as they provide learners with hands-on experience, especially those in practical study fields or production focused fields such as manufacturing.

Facilitators are able to pose suitable problems to the students and provide support and resources to facilitate the learning process. Learning factories provide the opportunity for experiential leaning whereby students gain experience through the application of empirical training allowing them to investigate, explore, reflect and synthesise the knowledge and skills. Targeting learning activities can be planned. This can include hands-on experiments, simulations, training exercises, labs, practical exercises, and information sharing sessions. Figure 2 shows a representation of the experiential learning that is achieved through learning factories.

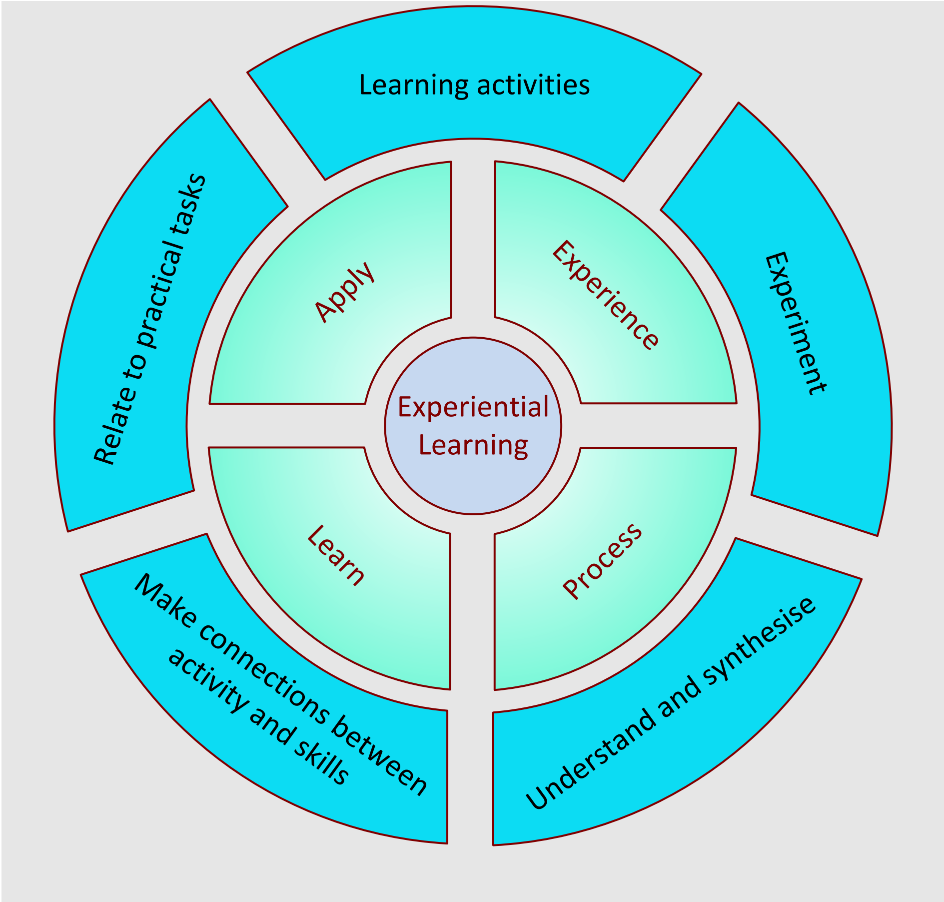

Figure 2: Experiential Learning

Experiences or learning activities can be selected based on their learning potential- whether it will enhance existing skills or pose a new situation/skill. During the experiential learning process in a learning factory, the learner will actively engage in processing information, understanding of concepts, investigating, constructing meaning, and overall being challenged to be creative or solution driven. After interacting in the domain of the learning activity/experience, knowledge will feed into the minds of the learner which then has to be processed. Through the initial observation and latter reflection, the learner can help understand the subject matter better, synthesis the knowledge and lead to more critical thinking and skills development. During this learning process, the learner will make connections between the different activities and skills. Later on, the learner can then apply the knowledge into other practical tasks.

4. Contextual Attributes of a Learning Factory

Learning factories facilitate action- and practice-based training and learning by compelling the learners to think and apply themselves rather than doing or acting only. As such learning factories are efficient in building competency and skills. Learning factories systematise and transfer domain-specific knowledge to the trainee. The implementation of learning factories is not limited and may therefore be adapted to suit custom requirements (Enke et. al, 2016).

Up until now, learning factories have not been typically used for the cybersecurity field. To initiate this application, the researchers have designed novel contextual attributes. Thus, with these contextual attributes, the usefulness of learning factories can be seen in Figure 3. The contextual attributes demonstrate the usefulness and application areas of Learning Factories. It aims to indicate what purpose learning factories have, how they can be operated, and the value gained from their use.

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 3: Contextual Attributes of Learning Factories

Figure 3 proposes five contextual attributes of learning factories, below is a brief description of each attribute.

- **Function** indicates the purpose and usefulness of learning factories such as training, skills development, competencies, and research. Enke, Tisch and Metternich refer to the purpose of training, education and research in their design dimension model of learning factories (2016).
- **Mode** refers to the planned objectives of learning factories in terms of achieving strategic partnerships, operational functionality or exchange mechanisms and information sharing
- **Benefits** includes the advantages of co-operation, collaboration, transformation and establishing a skilled workforce
- **Methodology** is the operating model of a cyber security learning factory that will provide for an agile, adaptive, active, responsive and engaging methodology. This is due to the vast number of activities that can be applied into a cyber security learning factory (scenarios, training, software, games, quizzes, simulations, practical exercises, tests, and presentations, videos)
- **Features** due to the remote capability of Information and Communication Technology, a cyber security learning factory has the advantageous features of allowing remote access, offering hybrid solutions and extendible capabilities (adapting or adding more labs, exercises, software, simulations, etc). Extendible capabilities are key in a fast-paced cyber security environment when the threat landscape and technologies are constantly evolving.

5. Conclusion

The global shortage of cyber security skills has cascaded to a national level. While most South African organisations at a private or public level have adopted using technological solutions to solve socio-economic problems, they do not possess the cyber security skills that are so relevant to ensure safety and security. Learning factories have been proposed in the manufacturing sector to offer a low-cost solution to replicating manufacturing environments and assisting in skills development. The authors provide adopting learning factories for the cyber security domain. To demonstrate the benefits of learning factories for the cyber security domain, a contextual attribute model was designed. This multi-dimension model highlights the qualities for a cyber security learning factory and aims to serve as the foundation for the development of cyber security learning factories. Future work will include delving deeper on methodologies for the design and execution of learning factories in the cyber domain.

References

Abele, E., Metternich, J., Tisch, M., Chryssolouris, G., Sihn, W., ElMaraghy, H., ... & Ranz, F. (2015). Learning factories for research, education, and training. *Procedia CiRp*, *32*, 1-6.

Baena, F., Guarin, A., Mora, J., Sauza, J., & Retat, S. (2017). Learning factory: The path to industry 4.0. Procedia manufacturing, 9, 73-80.

Barton, H & Delbridge, R. (2001). Development in the learning factory: Training human capital. Journal of European Industrial Training. 25. 465-472. 10.1108/03090590110410313.

Bloom, B. S. (1956). Engelhart MD, Furst EJ, Hill WH, Krathwohl DR. Taxonomy of educational objectives: the classification of educational goals. Handbook, 1.

Centre for Teaching & Learning, 2022, Experiential Learning, Available at https://www.bu.edu/ctl/guides/experiential-learning/, Accessed 7 September 2022.

Elbestawi, M., Centea, D., Singh, I., & Wanyama, T. (2018). SEPT learning factory for industry 4.0 education and applied research. Procedia manufacturing, 23, 249-254.

Enke, J & Tisch, M & Metternich, Jo. (2016). Learning Factory Requirements Analysis – Requirements of Learning Factory Stakeholders on Learning Factories. Procedia CIRP. 55. 224-229. 10.1016/j.procir.2016.07.026.

Faller, C., & Feldmüller, D. (2015). Industry 4.0 learning factory for regional SMEs. Procedia Cirp, 32, 88-91.

Kolb, D. A. (1984). Experiential learning: Experience as the source of learning and development. Englewood Cliffs, NJ: Prentice-Hall.

Mladineo, M., Gjeldum, N., & Veza, I. (2016). Lifelong Learning in Learning Factory. 23rd EurOMA Conference, Trondheim, Norway. https://www.researchgate.net/publication/349553755_Lifelong_Learning_in_Learning_Factory

Monetti, F. M., Boffa, E., Maffei, A., & de Giorgio, A. (2022). The Impact of Learning Factories on Teaching Lean Principles in an Assembly Environment. FAIM 2022: Flexible Automation and Intelligent Manufacturing International Conference, Detroit, MI, United States.

Powell, D. J. (2018). Kanban for lean production in high mix, low volume environments. IFAC-PapersOnLine, 51(11), 140-143.

Ramluckan, T., van Niekerk, B., & Leenen, L. (2019). Research Challenges for Cybersecurity and Cyberwarfare: A South African Perspective. 18th European Conference on Cyber Warfare and Security, Coimbra, Portugal. https://www.researchgate.net/publication/334327321_Research_Challenges_for_Cybersecurity_and_Cyberwarfare_A_South_African_Perspective.

Schofield A & Dwolatzky B. (2021). JCSE-IITPSA ICT Skills Survey, Available at https://www.iitpsa.org.za/wp-content/uploads/2021/09/2021-JCSE-IITPSA-ICT-Skills-Survey.pdf , Accessed 9 September 2022.

Švábenský, V., Cermak, M., Vykopal, J., & Laštovička, M. (2018). Enhancing cybersecurity skills by creating serious games. ITiCSE 2018: 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education, New York, NY, USA. https://doi.org/10.1145/3197091.3197123.