2023-10-10

Feature Model Construction Of Learning Factories Based On Authentic Learning Theory: A Case Study Of The School Of Micro-Nano Electronics At Zhejiang University

Peiyun XU
School of Public Affairs, Zhejiang University, Hangzhou, China, xupeiyun0719@163.com

Wei ZHANG
Institute of China's Science, Technology and Education Policy, Zhejiang University, Hangzhou, China, zhangwei2015@zju.edu.cn

Shuai WANG
School of Public Affairs, Zhejiang University, Hangzhou, China, wangshuaii2021@163.com

Feature Model Construction of Learning Factories Based on Authentic Learning Theory: A Case Study of the School of Micro-Nano Electronics at Zhejiang University

Xu Peiyun
School of Public Affairs, Zhejiang University,
Hangzhou, China
0009-0005-5025-9939

Zhang Wei[1]
Institute of China's Science, Technology and Education Policy, Zhejiang University,
Hangzhou, China
0009-0000-9072-3197

Wang Shuai
School of Public Affairs, Zhejiang University,
Hangzhou, China
0009-0001-6897-0412

***Conference Key Areas**: Engagement with Industry and Innovation, Fostering Engineering Education Research*
***Keywords**: Learning Factories; Authentic Learning; Model Construction; Case Study*

ABSTRACT

The learning factory is an educational environment that simulates real-world production systems to bridge the gap between theoretical knowledge gained from academic settings and practical skills required by businesses. To improve

[1] *Corresponding Author*
Zhang Wei
zhangwei2015@zju.edu.cn

the construction of learning factories at the early stage, a case study of the School of Micro-Nano Electronics at Zhejiang University has been conducted. First, an analysis framework based on authentic learning theory was developed to determine the critical elements of a learning factory based on four dimensions, including context authenticity, task authenticity, individual authenticity, and impact authenticity. Second, taking the School of Micro-Nano Electronics at Zhejiang University as the research object, qualitative analysis is utilized to further identify the essential elements of the construction model of learning factories. Additionally, an overemphasis on physical settings and a lack of industrial involvement have been identified. It suggests that it is essential to focus on effective industry engagement and strike a balance between the construction of the physical environment and the learning process. The findings provide construction insights for learning factories in their early stages of development.

1 INTRODUCTION

Over the past decade, concerns have emerged about engineering graduates lacking a comprehensive understanding of practical experience with real engineering sites and soft skills such as problem-solving, innovation, and management (Tell and Hoveskog, 2022). Hirudayaraj et al.(2021) reported that employers expressed deep concerns about the preparation of college graduates and revealed a great disconnect between what employers expect and the level of higher education considered as prepared for work. Thus, a significant emphasis has been placed on integrating practical experiences and real-world applications into engineering education. Several representative reports have been published, including *A Focus on Change, Engineering Education: Designing an Adaptive System, and The Engineer of 2020: Visions of Engineering in the New Century*, that urge engineers to return to the practice of engineering. This trend has led to the development of a new engineering education model based on learning factories, which have become more widely applied. Learning factories are highly authentic learning environments in which genuine products are manufactured in a simulated but life-like production setting. Following an action-oriented learning event within the Learning Factory, students may perform better in applications and develop more action-substantiating knowledge than after receiving conventional instruction (Cachay 2012; Rentzos et al. 2014). Since the learning factory has only been operating for a short period of time in China, the mechanism has yet to be perfected. How do learning scenarios simulate real-life industrial sites? What challenges do Chinese learning factories face during their early stages? Are still unclear. To improve the construction of learning factories in the early stages, a case study of the School of Micro-Nano Electronics at Zhejiang University will be conducted in this study.

2 LITERATURE REVIEW

2.1 Learning Factories

Learning factories are educational environments that simulate real production systems, allowing students to perform, evaluate, and reflect on their actions in an on-site learning approach (Wagner et al. 2012; Abele et al. 2015). These learning experiences aim to bridge the gap between the theoretical knowledge gained from academic settings and the practical skills necessary for the workplace (Bender et al. 2015).
In a literature review on learning factories, we typically find studies that explore the following areas. **(1) Definition and concept of learning factories.** The literature discusses learning factories' definitions and core concepts, highlighting their purpose, objectives, and critical features (Abele et al. 2017). They also investigate how learning factories differ from traditional educational approaches and how they enhance students' practical skills and industry readiness (Hamid et al. 2014) **(2) Pedagogical approaches and instructional methods.** Studies explore the pedagogical approaches and instructional methods employed in learning factories, including project-based learning, problem-based learning, experiential learning, and collaborative learning strategies (Bender et al. 2015). Researchers also investigate the effectiveness of these approaches in promoting active engagement, critical thinking, and interdisciplinary and soft skills development among students (Tisch et al. 2013). **(3) Facility design and technology integration.** Learning factories for production process improvement have been raised with lean methods and principles, like value stream analysis and design, just-in-time, line balancing, problem-solving, or job optimization (Abele et al. 2015). They also examine the role of modern manufacturing equipment, simulation tools, virtual reality, and data analytics in enhancing the learning experience and replicating real-world industrial environments (Kreimeier et al. 2022). **(4) Best practices and case studies.** A large amount of literature is case studies of different learning factories worldwide, for example, PTW at TU Darmstadt, the Learning and Innovation Factory (LIF) for Integrative Production Education at Vienna University of Technology (Erol et al. 2016), and the LPS Learning Factory at Ruhr University (Pittich et al. 2020). These examples highlight effective strategies, innovative approaches, and lessons learned from the establishment and operation of learning factories (Baena et al. 2017).

Overall, the majority of the literature primarily focuses on the experience summary of mature learning factory operational models in Western countries. On the one hand, it lacks a structured and scientific analytical framework, resulting in a lack of systematic analysis. On the other hand, little attention has been given to the challenges faced by learning factories during the early stages. Thus, we try to refine the construction model of learning factories structurally based on authentic learning theory. Furthermore, analyze the challenges learning factories face during their initial development phases.

2.2 Authentic learning framework

Authentic learning describes a pedagogical approach in which learning tasks are embedded within a real-world context. It offers students the opportunity to experience the same problem-solving challenges they face daily in the curriculum, allowing them to improve their problem-solving skills (Herrington 2014). It is an essential component of learning factories as it emphasizes the application of knowledge in real-world contexts. In a learning factory, students have the opportunity to work on authentic tasks and projects that simulate real-world manufacturing or production processes. By working on authentic tasks, students develop a deeper understanding of the subject matter, acquire practical skills, and apply their theoretical knowledge in a practical setting.

In order to explore the construction mode of learning factories in a more structured manner, it is necessary to bring in the analytical framework of authentic learning theory. This study mainly draws upon the authentic learning framework developed by Strobel et al. (2013). As shown in Table 1, it includes four dimensions, contextual authenticity, task authenticity, personal authenticity, and impact authenticity. Contextual authenticity refers to the resemblance between learning and real-world contexts. Task authenticity focuses on constructivist-type learning tasks in which students may be challenged to make decisions in practical contexts. Personal authenticity includes actions that make an experience authentic on a personal level, such as self-exploration. Impact authenticity pertains to the effective application of students' learning outcomes or activity products in real engineering contexts beyond school. These four dimensions of authenticity are conceptualized as bringing the learner closer to the realities of the workplace.

3 METHODOLOGY

This study adopts a mixed-methods approach, combining primary and secondary data about the School of Micro-Nano Electronics at Zhejiang University. The School of Micro-Nano Electronics at Zhejiang University is a prestigious academic institution in China dedicated to research, education, and innovation in micro-nano electronics. It began operating its *CMOS integrated circuit chip design and manufacturing innovation platform* in 2022. The platform provides a complete process innovation environment that includes chip design, fabrication, testing, and characterization. Also, it provides advanced facilities and resources for research, including computer-aided design (CAD) tools, simulation software, cleanrooms for fabrication, testing, and measurement equipment, and a team of experienced researchers and engineers. This platform allows students to explore and advance the field of CMOS integrated circuit chip design and manufacture.

Primary data are collected primarily through telephone or e-mail interviews with teachers and students with experience on the platform. Secondary data are collected from sources such as the college's official website, news reports, and databases such as CNKI. Once all surveys were finished, the researchers organized the codes into groups and constructed themes by describing the relationship between the grouped codes. A total of 252 items were included in the final corpus of studies.

Table 1. Coding Results

Code	Definition	N	%
Context authenticity	What makes a context is or resembles a professional context?	94	37.3%
Task authenticity	What makes activities resemble real-world activities?	42	16.7%
Personal authenticity	What makes experiences authentic on a personal level?	25	9.9%
Impact authenticity	What impacts can authentic experiences deliver?	91	36.1%

4 RESULTS

Through the analysis, we identified four important themes, including **(1) Context authenticity, (2) Task authenticity, (3) Personal authenticity,** and **(4) Impact authenticity**. In the following section, we will describe each of them. As a reminder, when participants' quotes are used, they are italicized, and themes appear in bold italics.

4.1 Context authenticity

Learning factories are designed to provide practice contexts that closely resemble real-world settings. This theme constitutes 94 of the 252 items, which is the largest category. In order to meet learners' practice needs, a focus on context authenticity is placed on both a production context and an interactive context. **(1) Real production context.** The real production context is represented by 38 items, which indicates a strong focus on the physical layout of the facilities to support the intended operations. An assembly line equipped with equipment, machinery, and software similar to or identical to the real-production settings has been adopted. Such as 3D printers, robotics systems, and data analytics tools. Students learned how to operate and optimize their use, as physical objects can provide engagement. Participant 1-3 said, *" Cutting-edge equipment, such as photolithography machines, helped us become familiar with the tools used in our future careers."* Additionally, factors such as available space, safety protocols, and ergonomics should be considered to ensure the facility is conducive to simulations of real-world manufacturing scenarios. **(2) Real interaction context.** 56 items are included about the real interactive context. Learning factories engage with universities, industries, and the government to establish partnerships for resource support, joint projects, and knowledge exchange. Interactions with the government account for the most with 40 items, which reflects the top-down characteristics of the learning factory construction in China. Governments provide overall direction, allocate resources, and monitor learning factories' performance. As participant 6-4 expressed, *"It was initially funded by governments, including infrastructure grants by governments of Zhejiang Province, Hangzhou City, Xiaoshan District, and Zhejiang University. "* Surprisingly, enterprises show little interest in learning factories as industry involvement provides valuable insights, mentorship opportunities, and exposure to real-world challenges. This construct has yet to be included in many of the most widely cited examples of learning factories in other countries.

4.2 Task authenticity

Task authenticity ranked third with 42 items. Moreover, the majority referred to Practices of full product life cycle with 25 items, followed by Real Problem-based with 10 items, and Follow Manufacturing Standards with 7 items. **(1) Real Problem-based**. In contrast to simulated or theoretical exercises, the learning factory provides an environment where students can solve real-world problems encountered in industrial settings. A real problem can be presented in various ways, for example, as a topic for competitions, a project to be contracted out to schools, or as a case study. Real problems can be complex, dynamic, and ambiguous and need to be solved within a tight budget and limited time. By engaging with real problems in a controlled learning environment, students gain first-hand experience tackling complex issues and developing practical solutions. According to participant 4-5, "*the program provides students with the opportunity to confront industry-specific challenges directly and improves their ability to think critically and solve problems continuously."* **(2) Practices of full product life cycle.** Instead of being pure technical demonstrators, learning factories serve as venues for students to participate at all stages of a product's life. It includes product development, production, distribution, marketing, and use. The majority of the items focused on the production stage. This stage emphasizes efficiency, quality assurance, and meeting production targets, with 16 items. Students gain hands-on experience using manufacturing equipment, interpreting data, conducting experiments, and implementing solutions. By incorporating practices related to the full product life cycle, learning factories provide students with a holistic perspective on product development and management. Participants 12-2 commented, *"We gain a deeper understanding and experience of integrated circuit design and manufacturing processes."* **(3) Follow manufacturing standards.** Manufacturing standards are followed to ensure consistent quality, safety, and efficiency. Also, by aligning with standards, students develop critical attributes such as attention to detail, precision, and protocol adherence. It prepares them for a smooth transition into professional roles. Participant 3-5 stated, *"The 55nm process chip has a width of no more than 0.946mm and a length of no more than 1.96mm. "*

4.3 Personal authenticity

Personal authenticity takes up a tiny proportion, with only 25 specific items. There are 11 items related to Enhancing Students' Subjectivity and 14 items related to Transforming Teachers' Roles. **(1) Enhance Students' Subjectivity**. Rather than learning through interaction with a single perspective (the teacher's), students are encouraged to take ownership of their learning, set goals, and make decisions regarding their projects and activities. They are also encouraged to articulate, negotiate, and defend their growing understanding through peer and teacher interactions. Participant 22-9 said, *" This activity aims to showcase students' outstanding performance and encourage academic exchange, enabling students to share their research freely."* Furthermore, a more significant proportion of elective courses have been provided in the curriculum to encourage personalized learning based on the capabilities of each student. Students are able to develop a sense of autonomy and agency through the enhancement of their subjectivity, which is essential for their personal and professional development. **(2) Transform the teacher's role.** The teacher's role has evolved from a traditional instructor to a scaffolder in the learning factory. Participant 10-2 introduced that *"Teachers adopt interactive teaching methods such as peer teaching, discussion sessions, and flipped classrooms."* While teachers can still play a crucial role in supporting students' learning, providing guidance, and sharing their practical knowledge and expertise, the critical difference is that students determine when and how the support is delivered. The scaffolding is gradually removed once the child can perform the tasks on his or her own.

4.4 Impact authenticity

Impact authenticity ranked second with 91 items. The most critical items were human capital development with 49 items, followed by Knowledge production with 31 items, and Generating economic benefits with 11 items. **(1) Human Capital Development.** First, practical learning experiences enable students to develop technical skills directly transferable to industry settings. Second, learning factories foster a collaborative environment where students from different disciplines work together on interdisciplinary projects. This collaboration promotes teamwork, effective communication, and cross-disciplinary work. Third, learning factories promote a growth mindset, encouraging students to embrace lifelong learning and adapt to changing industry dynamics. By developing these skills, students are enhanced in their employability and prepared for a smooth transition into the workplace. As Participant 4-9 said that *"The employment rate in 2021 was 100%, with graduates being employed in top-tier companies such as Texas Instruments, Cisco, and Huawei. "* **(2)Knowledge production.** Learning factories provide a platform for industry-driven innovation. Learning factories provide a platform for industry-driven innovation. Researchers and students can collaborate on industry challenges and develop practical solutions, where academic knowledge and research can be applied to develop new technologies. For example, Participant 8-2 said: *"Learning factories attract corporate participation in joint research and development. Therefore, duplicate R&D investments are reduced, and 1.5-2 years are saved in the process of* *launching a new product. "* In addition, learning factories encourage interdisciplinary collaborations, leading to the generation of new insights. For example, Participant 10-2 said: *"We actively collaborate across disciplines, exploring the fundamental and common vital issues constraining the future development of technology and industry.* **(3)Generate economic benefits.** Students and researchers have the opportunity to explore creative ideas, develop prototypes, test innovative solutions, and generate valuable knowledge and intellectual property in learning factories. Research and innovation can lead to the development of new products, processes, and technologies, fostering economic growth and competitiveness. Participant 18-2's statement exemplifies:*" The learning factory serves as a test bed for hardware and software partners from the industry and as a demonstration facility for ongoing research projects. "* Also, by fostering an entrepreneurial mindset and providing access to entrepreneurial ecosystems, learning factories contribute to the creation of new enterprises and job opportunities, promoting economic growth and fostering a culture of innovation.

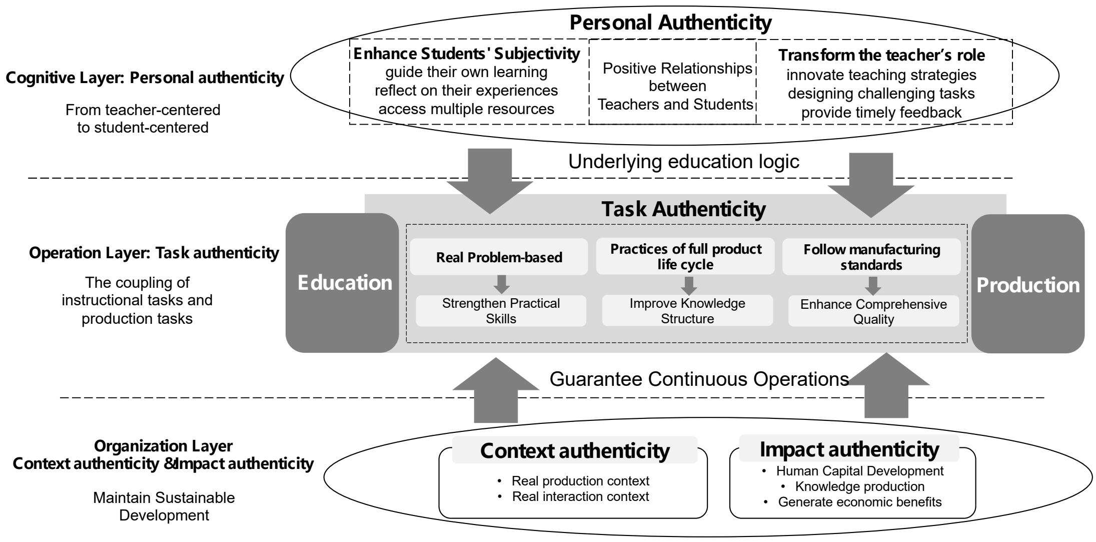

Fig. 1. Feature Model Construction of Learning Factories

5. DISCUSSION

As learning factories are relatively new and evolving in China, some common mistakes that have been observed are as follows.

First, a learning factory is not simply intended to demonstrate a simple copy of a production factory but an optimized learning process designed to foster the participants' ability to self-organize and act within authentic learning environments. However, some institutions mistakenly believe that merely creating a well-equipped physical space will automatically lead to effective learning experiences. Also, the desire to attract attention or funding may drive the emphasis on tangible and easily measurable elements such as machinery, technology, and workstations. However, physical settings are often prioritized in learning factories at the expense of pedagogical approaches, teacher

training, and curriculum development. A lack of engagement and involvement in the learning process may result from this imbalance, leading to a superficial learning experience. To mitigate these negative effects, learning factories need to strike a balance between the physical environment and the learning process. It involves developing learner-centered approaches, focusing on pedagogical innovation, and aligning the learning process with the physical environment. A strong emphasis should be placed on active learning methods, problem-based learning, and real-world projects that engage the students and encourage critical thinking, creativity, and teamwork.
Second, there needs to be more industrial interaction and economic benefits associated with learning factories in China. The pure operation of a learning factory focused on providing a hands-on learning environment for students may not be economically sustainable due to significant investments in equipment, facilities, and personnel. Furthermore, a lack of engagement from enterprises may prevent students from being exposed to the latest industry requirements, trends, and technologies. There could be several reasons why learning factories in China lack engagement from enterprises. First, enterprises may perceive learning factories as primarily focused on educational purposes rather than directly benefiting their business operations. They may view them as separate from their core activities and not see a clear link between participation in learning factories and achieving their business objectives. Moreover, some small and medium-sized businesses may lack the financial resources, personnel, and infrastructure to engage actively in learning factories. For the purpose of not only building up but also continuously operating. It is important to ensure that industry partners are actively involved in designing and operating learning factories. It can be achieved through effective communication, showcasing successful case studies, demonstrating the practical benefits to enterprises, and fostering partnerships and collaborations between academia and industry.

6. CONCLUSION

The learning factory is an innovative educational approach that integrates theory and practice by simulating real-world manufacturing environments. It provides students with hands-on learning experiences and practical training in production, process optimization, and problem-solving. In this study, we are interested in the feature model construction of learning factories. A framework based on authentic learning theory was developed based on four dimensions: context authenticity, task authenticity, individual authenticity, and impact authenticity. Additionally, we used qualitative analysis to identify the essential elements of the learning factory model at the School of Micro-Nano Electronics at Zhejiang University. And an overemphasis on physical settings and a lack of industrial involvement have been identified.

REFERENCES

[1] Abele, E., Chryssolouris, G., Sihn, W., Metternich, J., ElMaraghy, H., Seliger, G., Sivard, G., ElMaraghy, W., Hummel, V., Tisch, M.,and Seifermann, S. 2017. "Learning factories for future oriented research and education in manufacturing". CIRP annals, 66(2), 803-826. https://doi.org/10.1016/j.cirp.2017.05.005

[2] Abele, E., Metternich, J., Tisch, M., Chryssolouris, G., Sihn, W., ElMaraghy, H., Hummel, V., and Ranz, F.2015. "Learning factories for research, education, and training". Procedia CiRp, 32, 1-6. https://doi.org/10.1016/j.procir.2015.02.187

[3] Bender, B., Kreimeier, D., Herzog, M., and Wienbruch, T. 2015. "Learning factory 2.0–integrated view of product development and production". Procedia CIRP, 32, 98-103. https://doi.org/10.1016/j.procir.2015.02.226

[4] Baena, F., Guarin, A., Mora, J., Sauza, J., and Retat, S. 2017. "Learning factory: The path to industry 4.0". Procedia manufacturing, 9, 73-80. https://doi.org/10.1016/j.promfg.2017.04.022

[5] Cachay, J., Wennemer, J., Abele, E., and Tenberg, R. 2012. "Study on action-oriented learning with a Learning Factory approach". Procedia-Social and Behavioral Sciences, 55, 1144-1153. https://doi.org/10.1016/j.sbspro.2012.09.608

[6] Erol, S., Jäger, A., Hold, P., Ott, K., and Sihn, W. 2016. "Tangible Industry 4.0: a scenario-based approach to learning for the future of production". Procedia CiRp, 54, 13-18. https://doi.org/10.1016/j.procir.2016.03.162

[7] Hamid, M. H. M. I., Masrom, M., and Salim, K. R. 2014. "Review of learning models for production based education training in technical education". International Conference on Teaching and Learning in Computing and Engineering.IEEE, 2014. 206-211. https://doi.org/10.1109/LaTiCE.2014.47

[8] Herrington, J., Reeves, T. C., and Oliver, R. 2014. *Authentic learning environments*. Springer New York.

[9] Hirudayaraj, M., Baker, R., Baker, F., & Eastman, M. 2021. "Soft skills for entry-level engineers: What employers want". Education Sciences, 11(10), 641. https://doi.org/10.3390/educsci11100641

[10]Kreimeier, D., Prinz, C., and Morlock, F. 2022. "Lernfabriken in Deutschland: Praktisches Lernen in einer Fertigungsumgebung zur Schulung von Ganzheitlichen Produktionssystemen". Zeitschrift für wirtschaftlichen Fabrikbetrieb, 108(10), 724-727. https://doi.org/10.1515/zwf-2013-0724

[11]Pittich, D., Tenberg, R., and Lensing, K. 2020. "Learning factories for complex competence acquisition". European Journal of Engineering Education, 45(2), 196-213. https://doi.org/10.1080/03043797.2019.1567691

[12]Rentzos, L., Doukas, M., Mavrikios D., and Chryssolouris G., 2014. "Integrating manufacturing education with industrial practice using teaching factory paradigm: A construction equipment application". Procedia CiRP, 17, 189-194. https://doi.org/10.1016/j.procir.2014.01.126

[13]Strobel, J., Wang, J., Weber, N. R., & Dyehouse, M. 2013. "The role of authenticity in design-based learning environments: The case of engineering education". Computers & Education, 64, 143-152. https://doi.org/10.1016/j.compedu.2012.11.026

[14]Tell, J. and Hoveskog, M. 2022. "Applied engineering education for soft skills in the context of sustainability and mobility". International Journal of Sustainability in Higher Education, Vol. 23 No. 8, pp. 324-336. https://doi.org/10.1108/IJSHE-07-2022-0202

[15]Tisch, M., Hertle, C., Cachay, J., Abele, E., Metternich, J., and Tenberg, R. 2013. "A systematic approach on developing action-oriented, competency-based Learning Factories". Procedia CiRp, 7, 580-585. https://doi.org/10.1016/j.procir.2013.06.036

[16]Wagner, U., AlGeddawy, T., ElMaraghy, H., and MŸller, E. 2012. "The state-of-the-art and prospects of learning factories". Procedia CiRP, 3, 109-114. https://doi.org/10.1016/j.procir.2012.07.020