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Challenges in the Design of Complex Systems

Tailor-Made Intelligence: A Design Framework of Cyber-Physical-Social Systems for Personalized Learning

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Abstract

With the progress of technology and society, manufacturing enterprises are continuously advancing towards intelligence and personalization. The high degree of interconnection among human society, cyber world, and physical systems will become a momentous feature of the manufacturing industry environment. Human and social factors are considered in the connection between cyber and physical world, i.e. cyber-physical-social systems (CPSS), to achieve high-quality perception and feedback. In 2040, a successful company should design personalized learning systems (PLS) for employees to strengthen industrial abilities based on what they have gained in university, and utilize them to accelerate enterprise development. Under cyber-physical-social circumstances, however, how to precisely process intricate, diverse and massive data to achieve continuous tailor-made assessment and prediction for different targets remains a thorny issue. In this paper, I define the crucial characteristics for future high-tech companies to maintain competitiveness and propose a design framework of cyber-physical-social systems for personalized learning (CPSSPL). This system contributes to the adaptability and comprehensive development of enterprises, and helps the enterprise retain a leading position globally.

Key Words
Cyber-Physical-Social Systems for Personalized Learning, Data Processing, System Design, Enterprise Management

Glossary

Tailor-Made Intelligence. The realization of digitization and intelligence for companies utilizing cyber technology based on market analysis and human factors.
Cyber-Physical-Social System (CPSS). A system integrating and coordinating computing, physics, and human resources.
Personalized Learning System (PLS). A learning system that can provide customized learning arrangements and measures based on characteristics and demands of the user.

1. Introduction

As the manufacturing industry advance, it is currently an important global trend for manufacturing enterprises that traditional systems and mobile devices currently are in transition towards intelligent systems and devices. In the context of cyber-physical-social systems, various information and databases concerning computing, physics and human resources, are integrated in a complex interconnected world, so as to fulfill intelligent enterprises and management in the future industrial system. Moreover, under the ever-changing environment of Industry 4.0, the management systems in a high-tech enterprise that are targeted at employees and products, require continuously learning and adjustments to satisfy personalization, one of the key characteristics of a new generation of intelligent manufacturing. In the year 2040, high-tech global manufacturing companies should utilize cyber-physical-social systems for personalized learning to accomplish company operations and industrial missions. Through seamless interaction and collaboration between human society, physical space and cyber world, companies with these systems will possess better adaptability and efficiency.

I foresee that by 2040 cyber-physical-social systems for personalized learning will be basically in a high-class mature stage, the evolution of which is as shown in Figure 1. Currently cyber-physical-social systems in companies can not only collect various data of manufacturing from fundamental facilities and make dynamic configuration and accurate measures, but also cooperate with consumers' preference and business model [1]. Furthermore, personalized learning systems (PLS) can precisely evaluate employees in different departments in real-time and customize what they are expected to learn, thus strengthening human resource quality and assisting them to cope with underlying challenges in smart manufacturing. More optimistically, I predict that in 2040 these two types of systems will be highly integrated more closely to enhance development of industrial management of human resource and product chain. They will possess the capability to optimize overall manufacturing process and internal operating circumstance of enterprises autonomously and intelligently.

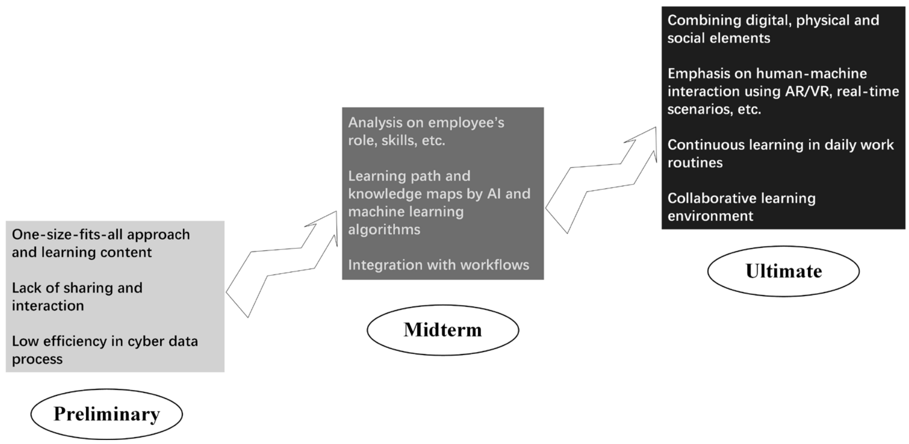


Figure 1. Evolution of CPSSPL

Therefore, how to design a cyber-physical-social system for personalized learning counts indeed for the sake of performance and efficiency. In this paper, we answer four questions:

- How do we match and personalize what the employee should learn and evaluate the learning performance continuously?
- How do we utilize the characteristics of the system to optimize the process of smart manufacturing of products?
- How do we preserve users' privacy security when it comes to data analysis and processing?
- How do we organize physical resource information through human-machine collaboration?

To address these questions, we propose a framework to design this type of systems. The rest of this paper is organized as follows. In Section 2, I define the characteristics of a successful manufacturing company in 2040 and introduce the framework of CPSSPL to facilitate the company staying competitive. In Section 3, I propose several research questions for the design and challenges of CPSSPL, and the hypotheses related to the research questions. In Section 4, I summarize the entire paper including emphasizing the importance of CPSSPL and highlighting future developments.

2. The Characteristics of a Competitive Company with Cyber-Physical-Social systems for Personalized Learning

2.1 Definition of cyber-physical-social systems for personalized learning

Traditionally, the cyber-physical systems (CPS) connect cyber and physical worlds through computation and physical processes, through which it is more reliable and efficient to manipulate physical entities under intelligent manufacturing backgrounds. Afterwards, the conception of cyber-physical-social was initially pointed out that the social and human dynamics should be regarded as an inseparable element while CPS design, so that the cyber space, the physical world and the human resource can be effectively coordinated and integrated, bringing us an era of intelligent enterprises and industries [2]. The cyber-physical-social systems are exactly designed for such a harmonious computing environment for intelligent management and decision-making.

Under the circumstances professional employees in manufacturing enterprises are required to work with some components in CPSS such as sensors, databases and so on. If we utilize CPSS into learning design, the cognitive behavior of learners can be systematically detected, thus predicting and personalizing recommendations based on numerous resources and databases. Through CPSSPL the continuous learning of employees and product manufacturing can be tightly bonded, achieving human-centric intelligent manufacturing and creating global competitiveness to companies in a newly-industrial era.

2.2 What is a successful company with CPSSPL?

As far as I am concerned, in 2040 a global enterprise is supposed to smoothly resolve plenty of challenges, especially the bottlenecks to promoting intelligent manufacturing through CPSSPL. Therefore, I present the key characteristics of keeping a high-tech manufacturing enterprise successful and competitive as shown in Figure 2, every of which I will describe in detail.

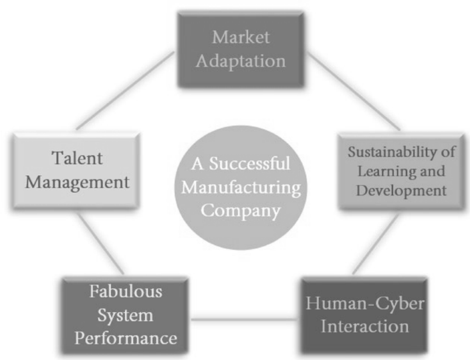


Figure 2. The Key Characteristics of a Successful Company in 2040

1) Agile identification and adaptation to the dynamic market and customer demands

As is known universally, customers' expectations and technology progress alter frequently in a fast-paced market, and therefore the high-tech manufacturing enterprises that can rapidly identify and adapt to these dynamic changes and demands are more likely to own competitive advantages. Agility and adaptation allow enterprises to implement modifications to improve efficiency with less costs, mitigate financial risk associated with factors out of anticipation and control, and also perceive new opportunities to stimulate innovative products into market.

In my design, cyber-physical-social systems for personalized learning can help companies analyze possible market trends and provide effective decisions, which will make companies more leading and profitable.

2) Excellent talent management

The emerging evolution of high-tech manufacturing industry require professional employees with not only more specialized skills, such as programming and design, but also excellent well-rounded abilities, because the market demands they will face are usually associated with multiple domains and are tough to satisfy if they have proficiency in only a particular line. Obviously there is a significant shortage of inter-disciplinary talents, so how to attract and manage these top talents becomes an essential. One the one hand, excellent talent management facilitates inspirations to develop new ideas by providing sufficient resources, and improves productivity and quality by ensuring they perform their own adept functions. On the other hand, considering the intense competition for talent and seriousness of brain drain, companies will invest more on top talent resources. Under the circumstances rationally arranging talent resources of a company ensures that the investment on them is worthwhile for retaining them, improving performance and reducing turnover rate.

In the future, manufacturing companies with cyber-physical-social systems for personalized learning have the ability to evaluate employees and offer customized learning plans to improve themselves, bringing about more competitiveness.

3) Sustainability of learning and development

For the purpose of continuous leading position, manufacturing companies should take into account how to foster staffs and how to maintain develop momentum. For employees, they are expected to acquire new knowledge and skills as they work in daily routine. For market development, environmental and industrial sustainability involves taking measures throughout the product chain, including the design, manufacturing, packaging, logistics and so on.

Nevertheless, there is no unified standard for sustainable manufacturing due to differences in company structure and knowledge base. In the future, through CPSSPL enterprises are able to self-evaluate manufacturing process and optimization requirements based on non-stop digital transformation and intelligent upgrading.

4) Great system performance

In the future, we naturally introduce cyber-physical-social systems for personalized learning into talent management and product chain achieved by data processing and smart decision-making. Faced with a large number of service targets and tasks, systems are required to have the capabilities of massive data processing and intelligent collaborative computing by multiple devices. In addition, future digital space includes ubiquitous interconnections of physical, social and other spaces, and it will be a challenge to coordinate and manage these resources when mixing human factors.

Hence, it is crucial to figure out a method to design CPSSPL to exert their performance. CPSSPL involve multi-disciplinary knowledge fusion and application of cutting-edge, and the utilization of great design is undoubtedly beneficial to high-tech global companies' comprehensive development.

5) Well-organized human-machine interaction

Since we consider human factors in cyber-physical systems as an organic part, companies need to realize coordination and interaction between humans and cyber systems when designing systems. Cyber technologies and techniques provide precise and efficient data analysis and smart decision-making, while the involvement of humans strengthens flexibility and social evaluation, which is hard to fulfill by only depending on machine learning. This shows that intelligent manufacturing enterprises will lay more emphasis on well-organized human-machine interaction to increase credit to operation of systems.

In a CPSSPL, we hope that humans and cyber systems coexist in different environments and their structural and integrated relationship can be demonstrated.

2.3 An design framework for CPSSPL

In order to facilitate a manufacturing company to gain the competencies identified in Section 2.2, I propose a framework for designing the cyber-physical-social system for personalized learning, as shown in Figure 3. In the year of 2040 when the industry is highly digital and intelligent, personalized learning systems in manufacturing companies are required to combine other systems about information processing and human-machine interaction. Against this backdrop we propose the personalized learning systems using cyber-physical-social networks.

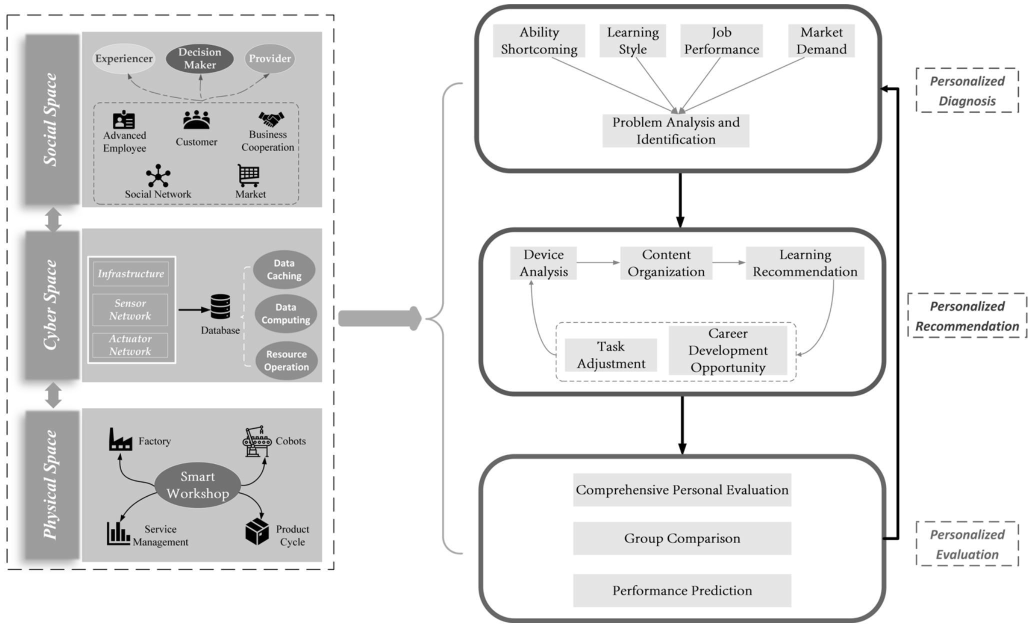


Figure 3. Design Framework of CPSSPL

There are three main spaces in CPSS. In a smart workshop of a high-tech manufacturing enterprise, the physical space includes the factory, numbers of collaborative robots, products and enterprise management. Then we use cyber data in these scenarios to achieve smart operations. With the help of massive data and resources from different infrastructures and controllers, the cyber space supports data caching, data computing and resource operation to accomplish information allocation, decision making and so on. At last in social space, different social users have different roles. For instance, they may be regarded as experiencers to provide feedback to systems, or providers to have the privilege to further examine the systems.

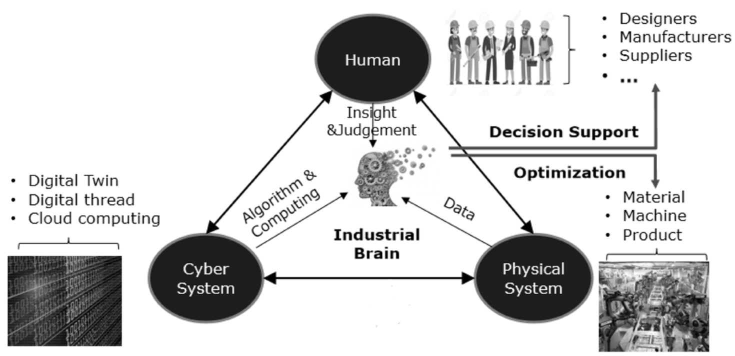


Figure 4. Industrial Brain in Intelligent Manufacturing [3]

With CPSS's excellent function of smart data processing as a base, it will be more comprehensive and industry-friendly for PLS to have tailor-made intelligence, which contain three modules. First users are diagnosed from different perspectives to confirm problems and improvement directions. Then the systems utilize the abilities of cyber-physical-social layer to provide personalized learning recommendation including theoretical content and actual adjustments in daily work. Finally employees are evaluated after learning and made comparisons with others in the same cluster, and their future development will be predicted based on present performance for next learning experience [4]. The cycle of these stages fulfills the target of continuous learning and thus the professional talents will be nurtured with inter-disciplinary skills and industrial brains [3], as shown in Figure 4.

3. Research Challenges for Designing and Developing Cyber-Physical-Social Systems for Personalized Learning

3.1 Employee training and assessment

In a future-oriented manufacturing company, it is a critical part to train and assess talented employees using data mining techniques, and these personalized learning systems should be tightly connected to enterprise planning and industrial environment. In this way not only can the learning programs be tailored to users' styles, knowledge and needs, but the systems also the systems can demonstrate superiority and more efficiency for boosting development of the company. In university students can learn theoretical knowledge and elementary hands-on practice of industrial engineering as a base. To continue to create value, we suggest five competencies employees need for adaptive learning:

1) Competency to observe, reflect and identify unfilled opportunities to create value.

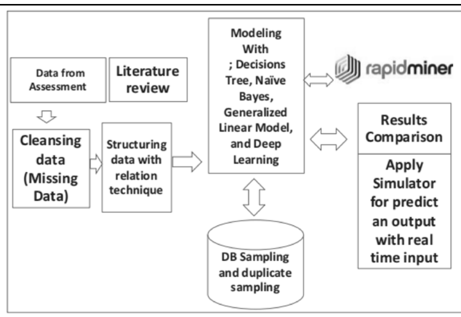
2) Competency to examine the opportunities critically.

3) Competency to ask questions, actively listen, reflect, and identify gaps in knowledge upon which a value proposition is based.

4) Competency to take a calculated risk.

5) Competency to plan, monitor and adapt to changing circumstances thereby staying the course and continuing to create value.

Research Question 1: How do we match and personalize what the employee should learn and evaluate the learning performance continuously?
Hypothesis 1: We use diverse data mining techniques into self-tutoring system to achieve learning assessment and recommendation by analyzing data set to discover and predict the individual capacity.



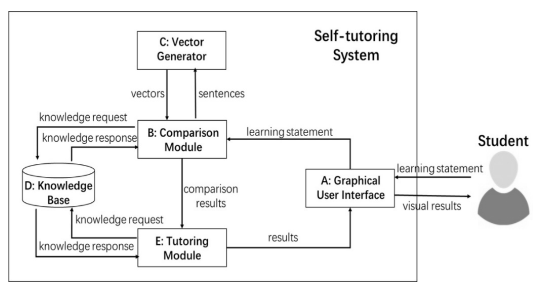


Figure 5. Framework of Data Mining Techniques [5] **Figure 6. Architecture of Self-Tutoring System [6]**

Technically we suggest that using data mining techniques is the most feasible method to complete arrangements for employees. Data science is a combination of techniques, mining, machine learning, predictive and data visualization. We take an example as shown in Figure 5. We choose MS SQL and MS Excel as data organizing tools, and Rapid Miner Application for modeling and computation. Comparative techniques applied in the experiments include Decision Tree, Naive Bayes, Generalized Linear Model, and Deep learning [5]. The data resources consist of employees' personal information, previous evaluations, analysis of market and society, etc. To cooperate with data mining we propose a design of self-tutoring system (See Figure 6), in which users can input their own learning statements and receive some useful information as feedback [6]. The employee users are regarded as both consumers and providers, meaning that the systems take into account the dynamic characteristics of humans like creativity and innovation, and that people in the system loop can be assigned tailor-made programs according to their customized requirements to cultivate an industrial brain.

3.2 Manufacturing design and optimization

The overall objective of our design is applying systems into smart manufacturing and its continuous optimization, and under the tendency of mass individualizing demands the manufacturing industry involves more and more social factors. Thus it becomes a challenge to handle the heterogeneity and sociality among large scale context data. To tackle it, we suggest adding social factors into the conception of Internet of Things, that is SIoT, to construct social structures among smart entities and prosumers.

Research Question 2: How do we utilize the characteristics of the system to optimize the process of smart manufacturing of products?
Hypothesis 2: We use the Social Internet of Things to promote the realization of mass personalized product manufacturing.

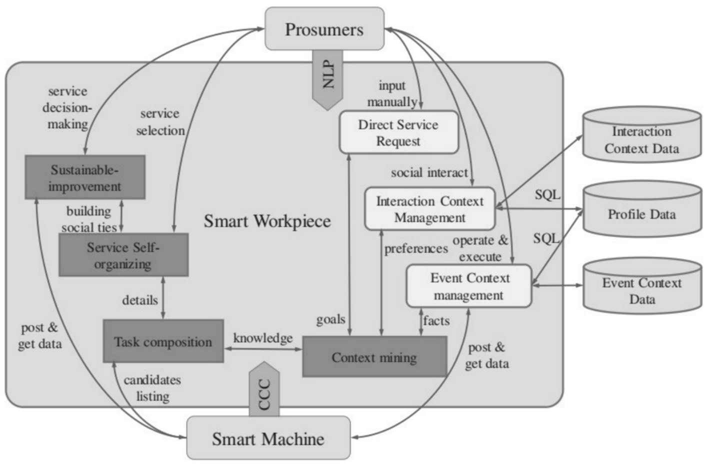


Figure 6. SIoT for Mass Individualizing Manufacturing [7]

In Figure 6 we demonstrate the procedure structure of SIoT among prosumers, smart workpieces and smart machines. The personalized needs of prosumers are captured and managed by smart workpieces, which can proactively interact and coordinate with smart machines to provide on-demand manufacturing services. The CPSS service management structure uses a feedback loop to provide necessary contextual data for sustainable improvement [7].

3.3 Privacy and security preservation

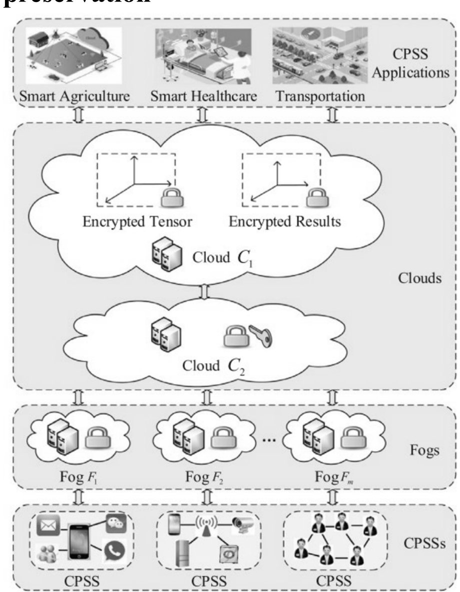


Figure 7. Privacy-Preserving Tensor Computation in CPSS [8]

The big data in CPSS are usually sent to the clouds or fogs for computation, while users are concerned about their privacy. Hence in the future there is an urgent need that the systems should balance pursuing profits of data resources and guaranteeing the individual's stringent privacy and security requirements.

Research Question 3: How do we preserve users' privacy security when it comes to data analysis and processing?
Hypothesis 3: We use the privacy-preserving tensor computation to protect users' privacy and security.

An effective perspective of solution is a privacy-preserving computation of tensor, which is a versatile tool for modeling data [9], and the framework is as shown in Figure 7. The data in CPSS are represented by a tensor model on the user side. The clouds and fogs with the encrypted tensor securely perform calculations of public/private keys to get encrypted results through privacy-preserving tensor operations. The results can be used in some applications, such as personalized learning, smart manufacturing for industrial companies [8].

3.4 Human-machine collaboration

As illustrated in Section 2.2, humans as an organic part of the systems are expected to collaborate with system components. Against this background, we suggest that in the future a well-functioning CPSSPL will possess the capability to coordinate human factors and system components, integrating human-based units and machine-based units.

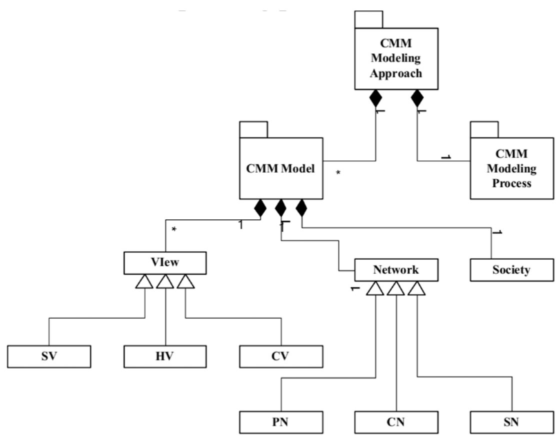


Figure 8. A Collaborative Modeling Method [10]

Research Question 4: How do we organize physical resource information through human-machine collaboration?
Hypothesis 4: We use a collaborative modeling method to realize human-machine integration, including the Coordination Theory based Multi-dimensions meta-model (CMM) and the modeling process of CMM.

In Figure 8, CMM is made up of View, Network and Society, and it contains three types of Views [10]. The coordination view defines the interdependency and the actions of CPSS components, the human view explains how humans integrate and interact with the CPSS components, and the system view presents the co-organizing relationship and the structural relationship among the components [1]. In this method the rationality and completeness of the system's human-machine collaboration can be fulfilled.

4. Closing Remarks

In a nutshell, cyber-physical-social systems for personalized learning will become a promising field for high-tech global design and manufacturing enterprises which seek comprehensive development and competency in future industrial market. With regard to human factors, these systems are required to allow humans to not only play a part of consumer or provider in the loop, but also continuously learn to conform to the social market. The design of this type of system thereby will be a significant bottleneck in 2040.

To successfully have the leading position in the industry, it's necessary for companies to agilely accommodate to market demands, wisely and sustainably manage talents and product chains, and design systems to process complicate big data with high-quality human-machine collaboration. Also, the challenges they need to overcome are basically divided into two parts. One is how to utilize data analyzed in CPSS to achieve employees' continuous and personalized learning and thereby cultivate industrial brain. And the other is the essentials of realizing smart manufacturing through CPSS, including SIoT for mass individualization, tensor computation for privacy preservation, and human-machine coordination using a CMM-based collaborative modeling method.

Consequently, the framework I propose will make a difference to the development of cyber-physical-social systems for personalized learning and the related technologies (See Figure 3). And its persistent progress and update can make us have a thorough understanding of it. In this way the enterprises will be globally competitive and be the frontrunner of high-tech design and manufacturing in 2040.

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