Chapter 3
Collaborative Systems and Environments for Future Working Life: Towards the Integration of Workers, Systems and Manufacturing Environments

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3.1 Introduction

The driving force for research in the area of technology-enhanced learning in work contexts is that the world of work changes rapidly. In Europe, digitalisation involves essentially all types of working life. Technology industry's urgent challenges range from the integration of new technologies' demographic change over to volatile business environments in general. The technology industry in Finland employs 290,000 people, and if counting indirect employment, the overall impact of the technology industry employs 700,000 persons, constituting 30% of the workforce and 50% of exports. According to Eurostat, around one in ten (9.4%) of all enterprises in the EU-28's nonfinancial business economy was considered a manufacturing company in 2012: a total of 2.1 million enterprises constituting 30 million skilled and unskilled jobs and generating EUR 1620 billion of value added. The EU exports consist mainly of manufactured products: their share has annually been around 80% of total EU exports.

The European manufacturing has been moving steadily to smaller lot sizes. This requires more flexible and agile production methods, adaptive systems and human know-how (Järvenpää et al. 2016; Lanz and Tuokko 2017). The key challenge in addressing the evolution of future education in the manufacturing sector involves developing skills and expertise as well as pedagogical and technological approaches that match the changing needs of today's and future workplaces. In order to stay competitive, companies and their workers need to be able to quickly adapt to new market conditions and customer needs, which require more and more problem-solving

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skills (Eberhard et al. 2015). To meet these needs, education calls for novel pedagogical and technological leaning approaches to enhance and trigger workers' skills. From a technological perspective, the emerging technologies include digital manufacturing, industrial Internet and cyber-physical systems (CPS). These technologies are characterised as having real-time, adaptive, decentralised decision-making and self-optimising features. Future work-life technologies are considered disruptive by nature; thus, when applied to practice, they will demand a completely new set of skills and mind-sets from workers (Berlin et al. 2016).

From a pedagogical perspective, the digital landscape influences society and its necessities regarding workers' skills (OECD 2016). The requirements of ever-evolving, technology-intensive working life are fluid and constantly transforming, and education should focus on teaching, enhancing and triggering these kinds of skills in future workers. The current trend seems to be that the importance of competency and skills is growing (Hilton 2008). More and more often in a dynamic manufacturing environment, work is based on the abilities to solve complex problems in technology-enhanced settings as well as inter-professional expertise and the shared construction of new knowledge. As a direct result of this advancement, the manufacturing sector is facing a need to improve shared problem-solving in technology-enhanced work settings to reach effective processes and work principles of future work-life needs (Berlin et al. 2016). For example, while individual skills of driving a machine were previously required in the manufacturing work for adults who have vocational education, in addition and even instead of these kinds of skills, future work-life requires that these workers have various kinds of multidomain knowledge and expertise in which they produce a new and useful output (an idea, understanding or solution) for the work community, i.e. workers with different backgrounds need to operate a machine as a team. Furthermore, it has been claimed that workers are also expected to promote innovations and shared work practices for work communities by uniting different social and technological resources. In sum, the requirements for professional skills and competences are increasing in all forms of work (Billett 2006; OECD 2016).

In the manufacturing sector, the current trend in workplaces seems to be that robotic and AI-based technologies are taking over routine tasks, leaving workers to accomplish non-routine tasks (Goos 2013). While the amount of blue-collar workplaces is decreasing, the increasing trend for future workplaces is within ICT-based manufacturing, automation and manufacturing servitisation (Manufacturing statistics 2016; Eberhard et al. 2015). Based on these trends, factories of the future are believed to need more skilled workers to meet future demands, while at the same time, a huge loss of corporate knowledge can occur if too many experienced workers retire simultaneously. The imperative to carry out economically profitable business remains a priority, but it will become more and more dependent on increasing the skills of the workforce. These global changes in work-life mean that the collective and individual success of workers depends not only on having discipline-based skills (such as practical maintenance expertise of a machine) but also on socio-cognitive skills (such as critical thinking, self-regulation and collaboration skills; Cress et al. 2015; Hyytinen 2015; Järvenoja et al. 2015). Currently, socio-cognitive skills and strategies for handling and producing new information play a crucial role in the emerging manufacturing environments. For example, the need for problem-solving abilities in technology-enhanced settings as well as the ability to use ICT tools in decision-making is increasing. Regarding decision-making, it is not only the need for the use of technology that is increasing but also the need for higher-order thinking and collaboration skills. It is crucial that workers understand cause-effect impacts in manufacturing chains. As a direct result of this advancement, companies must attract the right talent, successfully recruit them and then keep their skilled workforce for longer to achieve long-term business success. In essence, this means that employers must ensure the healthy working conditions for the personnel, cultivate the motivation and support the competence building of the workforce through continuous training (Berlin et al. 2016; Eberhard et al. 2015).

The aim of this chapter is to summarise the research in the integration of adults' skill and competences in problem-solving in TRE and future manufacturing environments. This is done particularly from the perspective of twenty-first-century skills and learning that the development of the new technologies in the workplace has forced us to rethink. In the following, first, adults' skills and competences are discussed based on our previous results of the large-scale assessment PIAAC data to make sense of the current state of the art. Second, based on this grounding, it will be further elaborated what this means to the technological and pedagogical design of workplace learning practices utilising emerging technological landscapes. Related to that, two different empirical examples will be presented to illustrate the variety of emerging technological landscapes meeting the needs of learning in the manufacturing context. We will illustrate the teaching factory approach focusing on collaboration between inter-professional workers with different education levels (vocational, applied, higher and continuing education) to improve future labour force skills to meet the needs of evolving manufacturing. Finally, we will illuminate how a simulation-based learning environment can be applied to understand complex machine systems in future manufacturing environments.

3.2 Adults' Skills and Competences Based on PIAAC

Work in the manufacturing sector is increasingly based on inter-professional teams working together. In practice, workers with different educational backgrounds (e.g. vocational education and training (VET) and higher education) are more and more often embedded to work together. Additionally, the manufacturing sector involves workers just starting their careers as well as those who are already midst of their careers. Keeping up with changing requirements of working life applies to all workers. In practice, this means providing learning experiences for workers from whom there are no course provisions to support their occupational development. It has been argued that workplace learning experiences offer the promise of realising important personal, social and economic purposes, including important equity outcomes—interests that are often closely intertwined (Billett et al. 2008). At the same time, from individual workers' perspective, opportunities for them to get involved in and remain in working life are dependent on their personal competences and skills (Keeley 2007). To be able to respond to the needs of learning in the context of manufacturing workplaces, we need to understand the relationship between the students' and workers' skills and their educational needs in these same realms. Adults' skills and competences are becoming an essential and fundamental prerequisite for prosperity and competitiveness. Furthermore, it has been suggested that the ability of companies and countries to respond to the information society's municipal challenges is essentially associated with workers' skills and competences.

The results of the PIAAC (the most comprehensive study of adult skills ever undertaken, led by the Organisation for Economic Co-operation and Development (OECD) showed that students' and adults' skills in literacy, numeracy and problem-solving in technology-rich environments (TREs) vary among the European countries. The general trend was that literacy, numeracy and problem-solving skills in TREs were highly correlated with each other at the individual level (see OECD 2013; Malin and Hämäläinen 2015). In short, adequate literacy is a prerequisite for good numeracy skills and problem-solving skills in TREs. Good numerical skills are also associated with good problem-solving skills, but the association is not quite as potent as literacy and the other two of these areas. Associations between literacy, numeracy and problem-solving skills in TREs and key socio-demographic background factors (gender, age, education, occupation, principal of activity, income, language and place of residence) are very similar to each other (OECD 2013; Malin et al. 2013). In Finland ($N = 5464$), literacy skills correlated with numeracy skills (0.86) and problem-solving skills in TREs (0.81). The correlation between the numeracy skills and problem-solving skills was 0.71 (Malin et al. 2013). This shows that people who have good reading skills, on average, also have good numeracy and problem-solving skills in TREs. Finally, in Finland adults seem to have overall high proficiency in problem-solving in TREs ($N = 4503$), which is highly needed in the future working life in the manufacturing sector (Hämäläinen et al. 2015). Thus, in general regarding meeting the needs of changing workplaces, the basic key competences of literacy, numeracy and problem-solving skills in TREs seem to be in reasonably good shape.

Despite the above advances, already in 2008 industrial companies were worried about the quality and quantity of vocational education and training (http://yle.fi/uutiset/3-5103963). Recent analysis of the PIAAC data establishes a genuine concern to be true (Hämäläinen et al. 2014, 2015, 2017, in press). Our analysis underlined the serious issue that, despite Finns' high proficiency in general for problem-solving in TREs, the majority of adults with a vocational education background have weak skills or lack the skills needed to solve problems in TREs. In detail, the results indicate the serious concern that more than two thirds of VET adults have weak skills or lack skills in solving problems in TREs. Furthermore, our findings indicate that over one fifth of VET adults are at risk regarding very weak problem-solving skills. To finish, our findings indicated that the likelihood of having weak problem-solving skills is six times higher for adults with VET than for those with at least upper secondary qualifications.

In our other study (*N* = 50,369), we focused on 11 European countries that participated in the PIAAC study (Hämäläinen et al. 2014). This same trend of VET adults' weak problem-solving skills to all these countries, as only 2.7% of the employed VET adults in the data showed strong problem-solving skills. Thus, the problem-solving skills of adults with a VET background in TREs seem to be often inadequate. In addition to describing differences in problem-solving skills, our research focussed also on understanding these variations (Hämäläinen et al. 2015) and finding the associations explaining good problem-solving skills (see Hämäläinen et al. 2017, in press). We found out that using skills and learning taking place in the workplace explained 10% of the variation. In particular, practicing numeracy at work and participation in job-related adult education and training seem to have a positive association with the likelihood of strong problem-solving performance. Finally, our analysis of VET adults (*N* = 12,929) with strong problem-solving skills in 11 European countries illustrated new knowledge with respect to the socio-demographic, work-related and everyday life background factors that contribute to successful VET adults' problem-solving skills. Specifically, a continuous process of development including non-formal and informal activity as well as learning taking place at work is associated with strong performance in problem-solving skills in TREs (Hämäläinen et al. 2017, in press).

In line with these challenges and possibilities, according to Billett et al. (2008), the whole the desired educational outcome is shifting from preparation for a specific occupation skills to the capacity to demonstrate professional skills and competence upon graduation, the need to ensure learning from the contributions of both settings means a greater focus on work-related learning and its effective integration in all forms of education. In practice, workers need to learn how to operate in changing environments (Dall'Alba 2009) and how to develop integrated knowledge and skills that allows them to understand the whole labour process and to deal with new and unpredictable situations (Eraut 2004). To meet these needs, in the future, companies must be able to make better advances in technological (e.g. smart machines and systems), contextual and social resources through effective working methods and the utilisation of context-aware information. However, the use of workplace learning technology, such as social software with built-in social intelligence for supporting inter-professional problem-solving in the work context(s), in a meaningful way is still needed in the Finnish manufacturing sector. As a timely solution for this, the following two research-based examples will illustrate how to integrate these design principles within the work environments of the manufacturing sector in a novel way.

3.3 Meeting the Needs for Continuous Learning in the Manufacturing Sector

To develop employees' competencies for manufacturing environments, traditional teaching methods have limited effects (Cachay et al. 2012; Eberhard et al. 2015). Manufacturing education, as identified by Manufuture (2006), will comprise a major driver towards that direction. As noted by Rentzos et al. (2014), teaching and training have not kept pace with the advances in technology, e.g. in integrating the theory and practice (Tynjälä et al. 2014). The current practice may not be adequate in providing the workers with the continuous delivery of engineering competencies and a strong multidisciplinary background. In addition, the lack in soft skills in comparison with IT skills has been widely acknowledged by employers (Tether et al. 2005) and more recently by the PIAAC study. Since the 1990s, sets of continuous education concepts have emerged. The learning factories for education, training and research have been built up in industry and academia. In recent years, learning factory initiatives have been elevated from a local to a European and then to a worldwide level (Eberhard et al. 2015).

The learning factories were first to emerge in the 1990s led by Penn State University with a concept called a 'learning factory'. It referred to interdisciplinary hands-on senior engineering design projects with strong links and interactions within the industry sector. The main goal of the learning factory concept is to provide an industrial production environment for education purposes inside the real industrial site. A college-wide infrastructure and a 2000 m^2 facility equipped with machines, materials and tools were established and utilised to support hundreds of industry-sponsored design projects in 1995 (Eberhard et al. 2015). The learning factory is to be used for systems that address both parts of the term—it should include elements of learning or teaching as well as a production environment (Wagner et al. 2012). The learning factory concept has been realised around Europe in various forms; however, they do not belong to any official curriculum. One of the successful concepts is a teaching factory. The teaching factory concept (Rentzos et al. 2014) is based on the knowledge triangle notion supporting both academic and industrial learning. The mission is to provide engineering activities and hands-on practice under industrial conditions for university students while taking up the research results and industrial learning activities for engineers and blue-collar workers. As an extension from the other approaches, a teaching factory involves two-way communication: factory-to-classroom (Rentzos et al. 2015).

A recent study (Järvenpää et al. 2016) conducted among Finnish manufacturing companies summarised that for the large OEM companies, one of the greatest challenges was the lack of information transparency between different departments and actors in the network. On the supplier side, the difficult forecasting and unexpected disturbances, e.g. rush orders or machine breakdowns, were identified as root causes for uncertainties in manufacturing operations management. In general, the identified challenges hindering competitiveness were very similar in different company types. One of the most visible challenges was that most of the companies did not have proper IT systems for production planning and control, such as a manufacturing execution system (MES) and advanced planning and scheduling (APS), to support rapid reactions to changes (Järvenpää et al. 2016). The adoption readability and competence level for utilising modern ICT tools was not very high among the companies. Furthermore, the study revealed that the understanding of the possibilities of current and emerging ICT technologies is relatively limited. The complexity of the emerging technologies and security (including both technical aspects and trust to partner) was considered a barrier. At the same time, the companies have realised the importance of continuous learning by adopting job circulation on the factory floor. Several of the interviewed companies mentioned that they intend to extend the job circulation among their workers on the factory floor.

Example 3.1 Integrating Physical and Virtual Learning Environment
A model for the teaching in industrial environments is the flexible manufacturing systems training centre (FMS TC) concept, which, unlike many others, has been an economically sustainable environment. The FMS TC is an industrial education environment that was established in 1997 by three different education providers, Tampere University of Technology, Tampere University of Applied Sciences and Tampere Vocational Education Institute and a local factory automation company. The driver behind establishing the FMS TC was the gap between education and work-life (Tynjälä 2008). The main focus of the environment is to provide a real-life factory environment for practical learning in different levels of education. In addition, in developing the factory environment, the critical points of TEL at work, such as easing the of use, flexibility and adaptability of the system, increasing learners' motivation, taking into account learners' needs as a starting point, creating managerial support, rethinking organisational culture, increasing the interaction between learners, facilitating learning and the inclusion of face-to-face components, were considered (see Tynjälä et al. 2014). The FMS TC is located within the company factory floor, yet it is separated from the daily production. The FMS TC provides a realistic production environment for learning different manufacturing and assembly processes, without compromising the real factory operations. The environment is constantly updated with the latest technologies (machinery, control architectures, user interfaces, etc.). The research results from the collaborative projects are implemented into the environment and demonstrated for the users. For example, the challenges of integrating new technologies in the authentic manufacturing context will indicate the technologies' maturity levels as well as their acceptance based on the students' and operators' feedback.

Table 3.1 summarises the usage of the environment on a yearly basis.

The aim of the environment is to trigger inter-professional teamwork and workplace learning (Collin et al. 2010). Specifically, from the company point of view, the environment is used for training their own customers to use the available machinery and control systems. For the Tredu, the main learning outcomes for students are the ability to operate flexible manufacturing systems and provide maintenance for single machines. The focus is on the skills relating to the management of daily operations in a semiautomated environment. The learning outcomes for TAMK students

Table 3.1 FMS TC use and user profiles

Partner	Learning goals	Education levels	Use (h/year)
Tampere University of Technology (TUT)	Problem-solving skills, decision-making, utilisation of ICT, FMS concept introduction, simulation of the system functionalities, programming of the system	3rd year to 4th year mechanical engineering and automation students (MSc Education)	64
Tampere University of Applied Sciences (TAMK)	Utilisation of ICT, programming of the system, robotics off-line programming	3rd year students (BSc Education)	132
Tampere Vocational College (Tredu)	Problem-solving skills, decision-making, maintenance of automation systems, off-line programming	Adult education	415
Fastems Oy Ab	Testing of the control software (SW) and user interfaces, training of FMS operators	Continuous education, system introductions to customers	232

are the ability to program the FMS and create off-line programs for the numerically controlled machines. The learning outcomes for the TUT students are to be able to program real and virtual systems. On the virtual side, different bottleneck simulations are used to create realistic problems to train students' critical thinking and problem-solving skills. These skills range from the mathematical problem modelling, constraints definition and implementation into the virtual production system. An example of this would be to model the part routes and material flow for the estimated production orders, run the simulation based on the defined constraints and then analyse bottlenecks and waiting times in the production. Then, apply different production control methods to existing model or change the layout of the factory; or product and material routing by adding new storage areas, warehouses or machinery; or combination of all in order to reach desired target state (Fig. 3.1).

Example 3.2 Simulation-Based Learning Environment for Understanding Complex Machine Systems

Traditionally in formal education, the emphasis has often been on reproducing what is already known, whereas workplace learning is striving for the creation of new knowledge (Goggins and Jahnke 2013). Future intelligent machines are semiautonomous or autonomous robotic systems, which are continuously adapting to working environments and self-learning tasks and processes. The continuous development of shared intelligence will change the role of many workers and their learning in this context. In practice, this enables them to create learning environments whereby the basic elements of professional expertise (i.e. practical, theoretical, self-regulative and sociocultural knowledge) can be integrated to enable workers to engage in innovative and transformative forms of learning rather than reproducing what is already known (Tynjälä et al. 2014). For example, in moving working machines, the role of the driver will more closely approximate an operator, who is controlling the operation via different user interfaces and makes control actions

Fig. 3.1 The physical environment (*left*) and digital twin of it (*right*)

only when needed. This means that the machine is capable of carrying out more complex tasks and operation chains, and therefore the operator is able to make decisions on a more general level. Thus, wider expertise related to the operation process is needed from the operator. In practice, workers need skills for acting in complex working entities in which they are surrounded by a variety of resources distributed across different technological settings and utilised both in individual and collaborative learning activities.

Illustrative working and learning environments are one solution for triggering above mentioned skills, and today, we can apply 3D techniques to empower the integration of different forms of expert knowledge (Söderström et al. 2012). A concrete example can be found from an automated mining system in which the loading of the minerals is fully automatic and the operator controls the loading process and the whole traffic of the loading machine fleet in mine (Schweikart and Soikkeli 2004). Another example of changing work descriptions is the maintenance technician who has to handle wider technology areas of intelligent machines. In his/her case, the machine will have more self-diagnostic tools to find possible items to be fixed or replaced. The industrial Internet will increase the data and knowledge of the machines significantly, creating a need to interpret the data. As a direct result of such advancement, in practice, simple routine tasks are performed automatically by computer-controlled machines, and workers need to tackle the specific problems that cannot be tackled automatically by computers or robotics. This means that workers face rapid and unexpected problem-solving situations in which knowledge is somehow implicit and directly integrated into practice. Therefore, we need novel learning solutions, such as virtual reality to help workers to developed adequate knowledge that guides them in future workplace problem-solving situations.

Virtual technologies allow students to learn in a way that is not possible in real life. From the perspective of learning, the crucial point relates to triggering competences. In particular, workers with limited previous experiences and low problem-solving skills in TREs need to develop complex arrangements that enable them to respond quickly to problem-solving situations in changing work conditions. Harteis and Billett (2013) suggested that high-level experts recognise patterns in complex arrangements that enable them to better respond spontaneously in ways that novices would not be able to in intuitive problem-solving situations. At their best, intelligent e-learning environments can trigger learners' abilities to react in these situations. In the following picture, we can see MetViro as an example of a virtual and intelligent e-learning environment for forest machine mechanics (Palonen et al. 2007). It is possible to see inside a 3D component while it is in use to see the fluid flow and pressure changes. 3D models created from production drawings allow viewers to see components as they appear in reality. Visualisation is backed by verified dynamic real-time simulation, which creates the movements of the components. The simulation guarantees rigorous response of motion caused different given control signals. Exact 3D models and verified, dynamic real-time simulation allow testing ground for new products or constructions. The generic structure in a virtual environment enables different new components to be tested in old systems or an entirely new system to be created. Furthermore, it is possible to disassemble and assemble components from parts, create and fix faulty situations and measure flow and pressure (Fig. 3.2).

3.4 Conclusions and Discussion

The digital landscape influences the necessary skills of workers in the manufacturing sector. In this chapter, we have summarised the challenges that Europe and Finland are facing in regard to future employment in the technology industry. Based on the PIAAC findings, it is evident that a considerable portion of the workforce will have increasing challenges in the future due to the lack of knowledge, analytical mind-set and practical competence in problem-solving. There is a critical notion that people with few prior successful experiences with fully applying the key information-processing skills may not have developed adequate knowledge that guides them in the structural changes in their future workplaces. At the same time, the job markets for uneducated and unskilled workers are decreasing. In the future, the manufacturing-related jobs in Europe are increasingly knowledge based, and

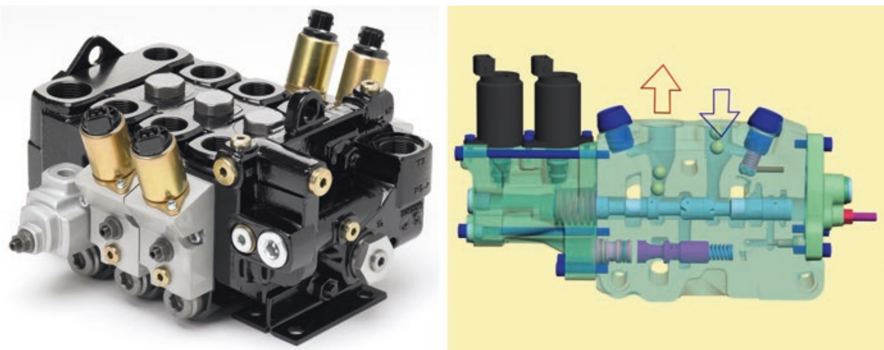

Fig. 3.2 The physical control valve (*left*) (Parker 2016) and digital twin of MetViro (*right*)

there is less need for manual labour due to the increasing level of automation in factories. Currently, approximately 10% of all employees in the automotive sector are regarded as ‘highly skilled’ (ACEA 2015). The share is increasing in the automotive as well as other sectors through digitalisation. Companies’ ability to benefit from the emerging technologies is also highly dependent on the ability of employees on all hierarchy levels to be self-organised in unknown situations and to find creative solutions (Adolph et al. 2014).

To respond to these changes in working life, it is necessary to recognise the need and magnitude for the change. In this chapter, we have highlighted how robotisation and digitalisation will change the skills needed in the future, especially in the field of industrial processes and environments. The systems will become more complex and autonomous, not only when designing but also when maintaining and upgrading the systems. As the complexity of the systems rises, so does the amount of design faults, malfunctions and other errors in operation. Future workers must be able to cope with the multitude of possibilities when operating and maintaining them. This will require the following:

- Strong problem-solving skills
- The ability to use ICT tools
- Decision-making skills (understanding cause-effect-impact chains)
- Multidomain knowledge
- Inter-professional collaboration skills

As a direct result of this advancement, workplaces and workers need to increase their flexibility and the adaptability of the jobs and effective work. This calls for novel learning approaches. According to Tynjälä (2013), future forms of learning should enable workers to engage in social and networked rather than individual learning, as well as in innovative and transformative rather than reproductive learning. However, moving to social and networked learning is not easy. For example, problems in social interaction have been identified as the most severe barrier to collaboration (Muilenburg and Berge 2005); therefore, it is clear that enabling interaction is not sufficient, but it should be stimulated and enabled. Recent research has highlighted the kinds and qualities of interactions, such as collaboration (Tynjälä et al. 2014) and experience sharing (Collin and Paloniemi 2008), that need to be triggered to meet the needs of future workers. Therefore, research-based knowledge needs to be fully applied in enhancing the pedagogical and educational development of vocational and higher education as well as workplace learning and lifelong learning to respond to the changing needs of the workplace. The chapter provided two research-based perspectives, continuous education in a training centre or in a teaching factory and an example of CPS, as evidence-based novel learning approaches that can guide educational efforts in designing ‘future’ learning at manufacturing sector.

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