

Vladova, Gergana; Wotschack, Philip; Paiva Lareiro, Patricia de; Krzywdzinski, Martin

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Development of problem-solving skills in a manufacturing context – a learning factory concept

Gergana Vladova^{*a,b}, Philip Wotschack^{b,c}, Patricia de Paiva Lareiro^{b,c}, Martin Krzywdzinski^{b,c}

^aUniversity of Potsdam, Karl-Marx-Str. 67, Potsdam 14482, Germany

^bWeizenbaum-Institut, Hardenbergstr. 32, Berlin 10623, Germany

^cWZB, Reichpietschufer 50, Berlin 10785, Germany

Abstract

The development and deployment of new technologies in industrial production impact employees' workflows and skill requirements. As the complexity of autonomous technology increases, its precise operation becomes more difficult to grasp for employees responsible for the operation, maintenance, and troubleshooting. This general problem of autonomous systems has been described in research as the 'ironies of automation'. While the need for knowledge and understanding of complex and abstract processes increases, the opportunity for direct feedback and learning is diminished. Subsequently, new challenges for training and skill development arise. Recent research has pointed to the importance of holistic process knowledge - as opposed to specific task knowledge - as an essential foundation for individual problem-solving competence. However, further research on the acquisition of problem-solving competences in an Industry 4.0 context is needed. This paper addresses this issue. We first report results from a laboratory experiment that was carried out in a learning factory, evidencing the importance of process knowledge. Based on our findings, we second develop a learning and training concept focusing on the problem-solving abilities of individuals and teams working with 'smart' self-regulating technologies. We expect that the problem-solving abilities of teams are particularly advantageous in smart, complex production settings. We discuss the validation of the concept in the learning factory that will start this year.

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Keywords: team, problem-solving, assistance systems, experimental study, ironies of automation

1. Introduction

Nowadays, autonomous technical systems are becoming more and more critical in many areas. At the same time, the complexity of the technology increases, and its accurate functioning becomes more difficult to grasp for employees responsible for the operation, maintenance, and troubleshooting. The demand for knowledge and understanding of complex and abstract processes is increasing [1], while the possibility for direct feedback and learning is diminishing. This general problem of autonomous technology has been described in research as the 'ironies of automation' [2]. 'Smart' assistance systems are intended to guide employees in solving the problem. This, however, requires new learning, training, and work processes that are organized and designed to convey the new skills and knowledge successfully. The problem-solving abilities of employees gain importance. However, research lacks how they can be developed in work processes characterized by increasingly complex and autonomous technology [2, 3]. Acquiring these skills is best possible through experience, and gaining experience in real situations would be fraught with fatal consequences. In pilot training, e.g., simulated training environments

* Corresponding author. Tel.: +49-331-9773356

E-mail address: gergana.vladova@wi.uni-potsdam.de

– as a convenient alternative – have been used for years. In the production sector, learning factories offer the comparable possibility of simulated production environments for learning how to deal with processes and errors.

2. Problem-solving in smart industrial manufacturing – an experimental learning factory study

In this paper, we introduce a learning framework for the development of problem-solving capacities of employees in the Industry 4.0 context. Problem-solving in complex automated systems requires a collective sense-making process (i.e., communication). The knowledge of different actors is mobilized to identify the causes of the disruption and appropriate responses [4, 5]. Research shows that peers affect an individual's performance positively [6, 7], that team decisions are generally more rational and self-interested than individual choices [8, 9], and that how roles in the team are assigned plays a crucial role in this [10]. Advantages of group-decision making depend on context: when more profound levels of insight or analytical problem-solving and coordination are needed, group decision-making is advantageous [9].

Moreover, research examining creative tasks has shown that the findings from one task type are not necessarily transferable to others [11]. Several mechanisms can explain the advantages of group decision-making, such as bringing together more knowledge and information, integrating different perspectives leading to fewer 'blind spots', providing a change of perspectives through discussions, overcoming individual barriers and limitations (cognitive or affectional), change in the motivation and logic of action giving more weight to group benefits, and finally, a higher commitment to goals and solutions at the group level [9].

In an experimental study in 2019, we investigated employees' learning processes in a simulated production process environment [12]. The focus lies on how the information provided by an assistance system influences individual work performance (including problem-solving) compared with a situation where the learning via the assistance system is combined with a general introduction into the functioning of the work process at the beginning of the learning process. Following the idea and concept of constructivist learning [7], we expected that learners provided with process knowledge would better understand the work process and show higher motivation, leading to higher productivity, quality, and work satisfaction. At the same time, we expected differences among workers' ability to process and apply this additional information. Our findings widely confirm this: Overall, group differences remain relatively low, demonstrating the slightly better performance of participants who received additional training. We, however, also found evidence for considerable variation between groups of different achievement levels: Among the high achievers, the group with process knowledge performed significantly better, indicating a positive effect from additional holistic knowledge for skillful participants. In the intermediate group, this additional knowledge related to a trade-off between a slightly higher level of productivity and a lower level of quality (more errors). In the group of low achievers, additional holistic knowledge was related to significant losses in productivity, while quality was not affected. Both groups (with and without process knowledge) furthermore differ regarding the additional information they desire. Assistance-system-guided learning goes along with a stronger desire for practical advice provided by the system. In comparison, the brief introduction (provided by a human) goes along with a stronger desire for more profound knowledge and personal advice. However, many participants in both groups wanted human support and assistance. These results point to an overall limitation of digital assistance systems and the need to ensure team communication in work processes, particularly when solving more complex problems in smart, self-regulating production lines.

Based on the findings of our first experiment and previous studies on problem-solving in teams, we developed a learning concept including three learning settings focused on the problem-solving capacities of employees working in "smart" self-regulating production environments. We assume that the advantages of teams regarding problem-solving capacities will depend on the work context: Individual problem-solving is superior in simple (linear) work environments (like assembly lines), where problem-solving requires a lower level of process knowledge. However, problem-solving of teams will be advantageous in smart (more complex) work environments, where interacting and self-regulating machines require a deeper level of understanding. The study will start in the summer of 2022. Using a learning factory (the Centre for Industry 4.0 at the University of Potsdam), we aim to determine whether the learning settings are suitable for developing process-related and problem-solving competencies in the experimental environment. Furthermore, we aim to find out to what extent teamwork of co-workers leads to better problem-solving as compared to problem-solving based on information retrieved by an assistant system or an expert.

Our design and experimental setting (see figure 1) are based on Kolb's concept of experiential learning [13]. The main focus of our study is the problem-solving abilities of employees' in dependence of (three) specific resources they can use: (A) assistance system, (B) co-worker (team), (C) supervisor. We hypothesize that problem-solving of teams (as compared to problem-solving via advice from an assistance system or via help from a supervisor) will be advantageous in smart work environments, where interacting and self-regulating machines require a deeper level of understanding. In our opinion, problem-solving through team interaction can provide a much deeper understanding by exploiting the advantages of team cooperation [9].

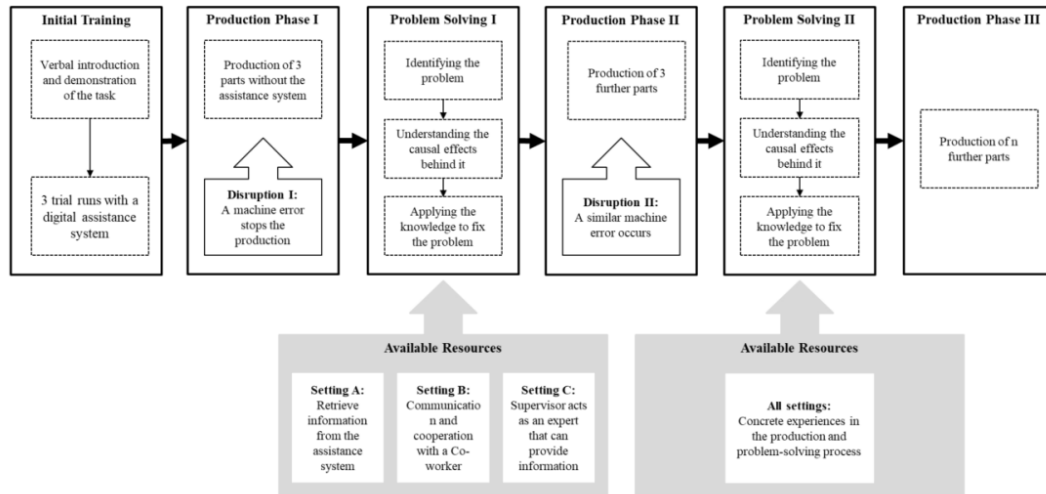


Fig. 1. Overview on the experimental setting based on the experiential learning model (Kolb, 1984) and the concept of action oriented learning

To determine the role of the three different treatments on the problem-solving abilities, we will measure the overall productivity in the different settings based on the number of produced workpieces and their quality and the required time for and the success of the problem-solving. Additionally, after the experiment, a survey will be conducted to determine how helpful the participants found the respective resources and how they experienced the problem-solving processes. Psychological aspects such as self-esteem and technology use resistance will be investigated and controlled by a standardized survey.

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