

A Critical Perspective on the Impact of Industry 4.0's New Professional Safety Management Skills on Process Safety Education

André Laurent ^{a*}, Bruno Fabiano ^b

^a Université de Lorraine, CNRS, Laboratoire Réactions et Génie des Procédés, UMR 7274, ENSIC 1 Rue Grandville, BP 20451, F – 54001 NANCY Cedex

^b Chemical and Environmental Engineering Department, Polytechnic School, University of Genoa, via Opera Pia 15, 16145 GENOA, Italy
andre.laurent@univ-lorraine.fr

Industry 4.0 will have an impact on the employees in the workplace. Indeed, the increasing automation, the real time-oriented control system and more generally digital technologies may disrupt and interfere with the quality, competence, safety and equity of employees and operators. It is, therefore, necessary to prepare a new workforce for the factory of the future. It is thus possible either to carry out partial or total retraining of current employees - or to educate new employees hired from the younger and newer generations. The most likely solution would be a hybrid proposition of the two previous possibilities. The paper first describes the need for new skills, necessary for industry 4.0 ambitions. Then, as a consequence, a global vision and the new trends for Education 4.0 are presented. Next, a proposal for the synthesis of applications for the preparation of process safety 4.0 curricula is discussed.

1. Introduction

In Europe, with the current rate of retirement of the baby boomers, more and more engineers are being placed in operational positions where safety, health and environment (SHE) is important and vital components of their work. The need for engineers to be better trained in SHE management, particularly in process safety 4.0, is underlined by industry and governmental authorities. This demand is now further accentuated by the disruption of digital technologies within the ongoing Industry 4.0 revolution, while the role of process engineering should include a critical and balanced application of new developments in data science and digital technology with fundamentals science and engineering principles (Pasman et al., 2021). Recent surveys targeted to current employees, university teachers and governmental institutions, evidenced strengths and drawbacks of the focus of current process safety training and in particular the scarcity and weakness of co-occurrence of topics, as indicated by keywords in publications between writings on industry 4.0 and on process safety (Gajek et al., 2021). The evident problem in the near future should be the shortage of skills that new jobs will demand. The current generation of safety employees came into organizations as Responsible Care® was being developed. In those days, it was common practice for junior engineers to have a senior engineering mentor and to have time to learn before acquiring higher levels of responsibility. Nowadays, both the process and manufacturing environments are quite different: corporations are more streamlined, outsource products to smaller specialized companies and are much more market-oriented. Each organization has fewer engineers. Indeed, it is not uncommon for graduating engineers to be hired into small companies where they are the sole engineer on staff. At the same time, societal demands on companies have increased. There are more and more varied regulations pertaining to the environment, health, safety and sustainable development. Graduates have more responsibility and less time to acquire the knowledge. Starting from the analysis of the current situation on the labour market from the perspective of employers and requirements for students, or graduates of Czech Republic universities Laciok et al. (2021) draw indications of general validity on the need for a paradigm shift towards the newly defined Safety 4.0 including a revision of the employee training for the factory of the future, accounting for new

technological hazards. Specifically, there is a need to reconsider the current approach towards the education and training of chemical engineering and process safety curricula and to develop new/advanced models that would be better aligned with the needs of both employers and future employees.

This article proposes to define a strategy for the development of process engineering and safety curricula for the factory of the future, by specifying the conceptual principles retained. The involvement of the different digital sectors is translated into specific requirements in the curriculum, with the collaboration of all stakeholders. The different routes for the practical implementation of the framework are respectively examined. The classical initial training route at university with the bachelor and master degrees is first commented on. The professional route with the on-job training and continuous professional learning is also examined. Some practical examples illustrating the approach are given. The final aim of this perspective article is to identify the skills required and to list some emerging training courses integrating digitalization in process safety and their contents.

2. A need for new skills, necessary for industry 4.0 ambitions

The evident problem in the near future could not be the lack of employment, but the shortage of skills that new jobs will demand. Faced with these changing contexts, several types of skills are needed. On the one hand, those of the “data scientists”, which are related to applied mathematics and algorithms. On the other hand, those of the “data engineers”, which concerns data engineering.

The *data scientist* is responsible for defining the methods, exact, statistical, or constructed by machine learning, necessary to obtain the desired results as well as the relevant data for the implementation of this method. It must then build the algorithm capable of implementing this method, as well as its computer programming, if necessary programming, if necessary parallel and distributed.

The *data engineer* focuses on four main activities:

- the integration of large volumes of data from a variety of sources;
- the transformation of this data through various cleansing, normalization and enrichment processes;
- analytical processes designed by data scientists;
- and decision-making processes to produce automated periodic reports, or visualizations on demand.

The skills required for Industry 4.0 employees must contribute to higher qualifications, especially in the field of engineering and information technologies. Benasova et al. (2019) divided skills into domain-general and domain-specific skills respectively called soft and hard skills. Hard skills are a set of professional requirements as theoretical and practical knowledge. Soft skills are a contribution of interpersonal people, social and communication skills. The proposed required skills of employees 4.0 are described in Table 1.

Table 1: Division into soft and hard skills required of Industry 4.0 (Benasova et al., 2019)

Hard skills	Soft skills
Language knowledge	Communication skills
Degrees, apprenticeships, certificates with technical or information focus	Flexibility
Machine operation	Self-discipline
Programming language	People management
Software knowledge	Time management
Cybersecurity knowledge	Emotional intelligence
Knowledge of data analysis	Critical thinking
Cloud computing	Creativity
Knowledge of artificial intelligence	Coordination with others
Knowledge of processes	Complex problem solving

Benasova et al, (2019) detailed, on the one hand, the required qualification and skills of professions of information technologies, such as informatics specialist, robot programmer, software engineer, data analyst and cybersecurity expert. In the same way, these authors described, on the other hand, the required exigencies for professionals of production, such as electronics technician, automation technician, production technician and manufacturing engineer. In the McKinsey analysis surveying 2135 executives, Ellingrud et al., (2020) evidenced those cultural and behavioural barriers are the most relevant challenges and proposed a generic scheme depicted in Fig. 1, to promote the transformation of current functions into new roles and skills in the analytical and digital fields. For example, in operational management, production and technology managers should be made aware of new technologies here internally. On the other hand, in a manufacturing unit, the central maintenance team could evolve into several different functions. If the skill combination, which the company needs for future roles, is well defined, Figure 1 enables these requirements to be compared with the skills available in its current workforce. It is then possible to plan how staff can be redeployed over time and identify

gaps that need to be filled to meet the needs of existing and new roles. During the planning phase, the company should also assess potential factors that may disrupt the reskilling project. The role of the existing human resource and training infrastructure is critical. But the willingness of the workforce to accept change should not be overlooked.

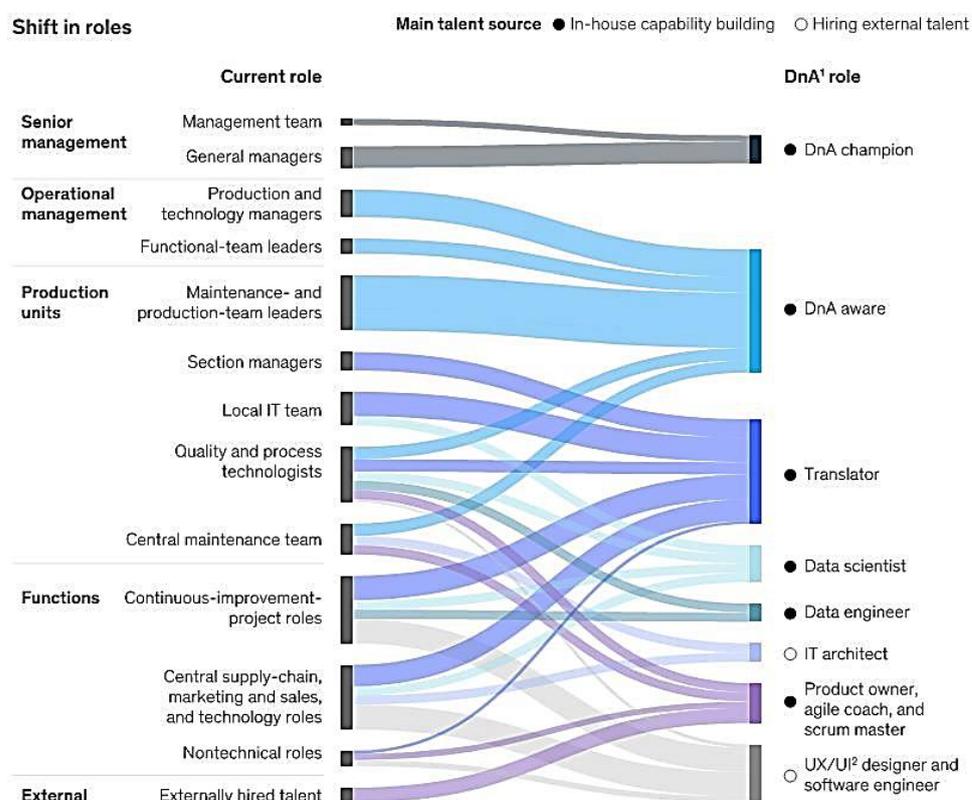


Figure 1: Creating the right talent pool for a digital and analytics transformation combines in-house capability building and hiring for specific roles (Ellingrud et al., 2020).

3. Vision and new trends of education 4.0

The vision of Education 4.0 should broadly include and meet the following elements:

- respond to the needs of the fourth industrial revolution, where man and machine align to enable new possibilities;
- harness the potential of digital technologies, personalised data, open content and the new humanity of this globally-connected, technology-powered world;
- set a plan for the future of learning - lifelong learning - from children's schooling to continuous learning in the workplace, to learning to play a better role in society.

Among the many discussions, innovations and general changes in the world of learning, Fisk (2017) has identified nine distinct trends (https://youtu.be/R__OTRRgtH8):

Diverse time and place - Students will have more opportunities to learn at different times in different places. eLearning tools facilitate opportunities for remote, self-paced learning. Classrooms will be flipped, which means the theoretical part is learned outside the classroom, whereas the practical part shall be taught face to face, interactively.

Personalized learning. - Students will learn with study tools that adapt to the capabilities of a student. This means above-average students shall be challenged with harder tasks and questions when a certain level is achieved. Students who experience difficulties with a subject will get the opportunity to practice more until they reach the required level. Students will be positively reinforced during their individual learning processes. This can result in positive learning experiences and will diminish the number of students losing confidence in their academic abilities. Furthermore, teachers will be able to see clearly which students need help in which areas.

Free choice - Though every subject that is taught aims for the same destination, the road leading towards that destination can vary per student. Alike to the personalized learning experience, students will be able to modify their learning process with tools they feel are necessary for them. Students will learn with different devices, different programs and techniques based on their own preferences.

Project-based - As careers are adapting to the future freelance economy, students of today will adapt to project-based learning and working. This means they have to learn how to apply their skills in shorter terms to a variety of situations. Students should already get acquainted with project-based learning in high school. This is when organizational, collaborative, and time management skills can be taught as basics that every student can use in their further academic careers.

Field experience - Because technology can facilitate more efficiency in certain domains, curricula will make room for skills that solely require human knowledge and face-to-face interaction. Thus, experience in 'the field' will be emphasized within courses. This means curricula will create more room for students to fulfil internships, mentoring projects and collaboration projects.

Data interpretation - Though mathematics is considered one of three literacies, it is without a doubt that the manual part of this literacy will become irrelevant in the near future. Computers will soon take care of every statistical analysis, describe and analyze data and predict future trends. Therefore, the human interpretation of these data will become a much more important part of future curricula. Applying the theoretical knowledge to numbers, and using human reasoning to infer logic and trends from these data will become a fundamental new aspect of this literacy.

Exams will change completely - As courseware platforms will assess students' capabilities at each step, measuring their competencies through Q&A might become irrelevant, or might not suffice. Many argue that exams are now designed in such a way, that students cram their materials, and forget the next day. As the factual knowledge of a student can be measured during their learning process, the application of their knowledge is best tested when they work on projects in the field.

Student ownership - Students will become more and more involved in forming their curricula. Maintaining a curriculum that is contemporary, up-to-date and useful is only realistic when professionals, as well as 'youngsters', are involved.

Mentoring will become more important - In 20 years, students will incorporate so much independence into their learning process, that mentoring will become fundamental to student success. Teachers will form a central point in the jungle of information that our students will be paving their way through.

4. Attempted applications to the preparation of a process safety 4.0 education

4.1 Global approach

Graham (2018), from Intelitek society, reported that the changes in industry 4.0 must have a direct impact on the way to build the education system for today's students. In order for this to change, the educational paradigms must be revisited. Transformations of the corresponding paradigms of current education are respectively: - the paradigm of the empty brain to be filled, - the requirement of basic knowledge - and the interference of the computer with thinking and learning in individual mode. The Education 4.0 learning system is based on fundamental principles of Education 4.0 such as the personalization of learning paths, formative assessment, mentoring, and the divergence and plurality of learner profiles. Education 4.0 needs to align with industry 4.0 as suggested in Table 2.

Table 2: Aligning industry 4.0 requirements with education 4.0 (Graham, 2018)

INDUSTRY	EDUCATION
Flexible production line	Tailor-made learning path
On-line quality control	Formative assessment
Workers monitor automation	Teachers become mentors
Custom products	Divergence and pluralism
System engineering	Education is the goal
Long-life learning	Continuous teachers learning

Regarding the application of these principles to the process safety discipline, Bohie et al (2020) have recommended guidelines for improving the effectiveness of process safety management systems in operating facilities, in particular for the development of the workforce of operators, engineers, managers and executives. Incomplete process safety knowledge and ownership across an organization can lead to inadequate prioritization and a higher level of risk-taking leading to incidents in operational facilities. A structured competency development program is required at all levels of the organization starting from shop floor operators, newly recruited engineers up to top executives. The current status of worker competency and the impacts of changing workplace dynamics need to be assessed and incorporated. Only then can effective training and continuing education programs be implemented that will meet industry requirements. The current retirement wave has resulted in reduced experience levels in the workplace in many industries. As a result, valuable knowledge on how to ensure safe operations are being lost. It should be noted that currently, process safety

courses are fully taught only in a few engineering curricula across European universities and not at technical colleges or trade schools (Kouwenhoven, 2021). A comprehensive process safety certificate program can be a valuable asset for students at both engineering and operator levels as they enter the workforce. Process safety certificate program for the two-year college program will be an important addition. This program might also be made available online for anyone wanting to improve their knowledge in process safety. Process safety responsibility must also be enhanced at all levels of technical management and this can be done effectively in several ways that support the program above. These include the following: - Incorporating active learning components in operators' training and education; - Holding Process safety workshops or boot camps for middle and senior management; - Encouraging new engineering hires to take online process safety courses and gain certification; - Holding process safety workshops for executive management not only to enhance their knowledge in process safety- but also to stress the critical importance of their support and participation in process safety program implementation; - Implement a risk-based decision-making training program. Such training would encompass risk-based decision management with the goal to provide guidance to improve the outcome of the critical technical decisions they will be faced with in the future. Companies can collaborate with institutes or centres that provide an array of courses for continuing education and professional development in the field of process safety and risk management to improve the core process safety knowledge of engineers working in different fields in the industry.

4.2 Examples of application

The review of the open literature identifies several publications on requirements and qualifications for education 4.0. For example, Benesova and Tupa (2017) and Benesova et al., (2018) described quantitatively the Bachelor's study program "Process management of industry 4.0". Haron (2018) discussed the challenge of education in the area of industrial revolution 4.0. Komenda et al., (2019) presented a practical approach to teaching digitalization strategies in cyber-physical production systems. Duever (2019) adjusted several approaches for teaching data science in the chemical engineering program. Laciok et al., (2020) reported the experimental implementation of virtual reality into the area of teaching occupational safety for industry 4.0. Jamiesen et al., (2020) developed an integrative framework to structure a case study approach for investigating chemical process safety. Bonfield et al., (2020) validated teaching and learning in the digital age with four case studies with different scenarios tested in three different universities (Australia, UK and Singapore). One of the best full-length papers relating to process safety concerns in process system digitalization was recently published by Khan et al., (2021). These authors have first listed, commented and discussed the detailed chemical engineering undergraduate courses (4 years) taught at six selected universities (Canada, USA, UK, Malaysia, Republic of South Africa). By considering that Industry 4.0 offers the opportunity to integrate and leverage current technologies and modelling approaches to improve process safety, Khan et al., (2021) have then designed a comprehensive educational content project, based on the respective four areas of learning as abnormal situation management – process automation and control – process reliability – process safety and asset integrity. They suggest, for each area, the different main topics and detailed subtopics to address process safety concerns with respect to process system digitalization. Table 3 illustrates here an oversimplification of the original presentation recapitulating only the subject areas and the main topics. The detailed subtopics are listed in Khan et al., (2021).

5. Conclusions

To meet the immediate needs and future evolution of Industry 4.0, it is imperative to create new occupations and to retrain some of the functions occupied by current employees. The priority for creation lies in the jobs of data scientists and data engineers. The partial or complete conversion of certain current functions implies, in the short term, ensuring at least a comprehensible and constructive dialogue with specialists in digital technologies and artificial intelligence. In the professions of chemical engineering, process engineering and process safety, there is a need to gradually retrain generations of employees with professional experience through short upgrades, for example in the use of digital twins, without forgetting the impact of their natural reluctance to change. The new generations of future young employees, already familiar with the IoT, should graduate from various mixed hybrid courses, whose pedagogical syllabus should be inspired by the content of Table 3. The elective approach is often an effective way of introducing new elements and gradually reconfiguring the syllabus. The paper advocates that appropriate degree courses of chemical engineering and process safety should include the study of the new constraint of digitalization 4.0 through an integrated approach. The conclusions of the paper should be of interest to those who manage existing academic curricula and to those planning a new integrated digitalization syllabus. It is the responsibility of all stakeholders in the University, Industry and learning apprentice centres to promote this approach to designing for a new modern safety engineering program.

Table 3: Oversimplification of the presentation of subject areas and main topics (Khan et al., 2021)

Abnormal situation management	Process automation and control	Process reliability	Process safety and asset integrity
Introduction	State-space theory	Failure distribution	Accident modelling
Model-based monitoring technique	Estimation of states	Time-dependent failure models	Consequences modelling
Data-based monitoring technique	Introduction to process Modelling and parameter estimation	System reliability	The human factor in engineering
Alarm management	Steps in model building Parameter estimation Computing the estimate Model validation methods Analysis of multivariable Systems Controller design	State-dependent systems Design for reliability Maintainability Availability	Risk assessment Probabilistic risk Assessment Uncertain analysis Asset integrity

References

- Behie S. W., Halim S. Z., Efav B., O'Connor T. M., Quddus N., 2020, Guidance for improve the effectiveness of process safety management system in operating facilities, *Journal of Loss Prevention in the Process Industries*, 68, 104257, 1 – 11.
- Benesova A., Tupa, J., 2017, Requirements for education and qualification of people in Industry 4.0, *Procedia Manufacturing*, 10, 2195-2202.
- Benesova A., Hirman M., Steiner F., Tupa J., 2019, Requirements for education 4.0 and study programs within industry 4.0, *Proceedings of the International Conference on Industrial Engineering and Operations Management*, IEOM Society Interactions, Pilsen, Czech Republic, July 23 -26, 2019, 1678 – 168.
- Bonfield C. A., Salter M., Longmuir A., Benson M., Adachi C., 2020, Transformation or evolution? Education 4.0, teaching and learning in the digital age, *Higher Education Pedagogies*, 5(1), 223 – 24.
- Duever T., 2019, Data science in chemical engineering curriculum, *Processes*, 7, 830, 1 – 7.
- Ellingrud K., Gupta R., Salguero J., 2020, Building the vital skills for the future of work in operations, Article, <https://www.mckinsey.com/business-functions/operations/our-insights/building-the-vital-skills-for-the-future-of-work-in-operations>.
- Fisk P., 2017, Education 4.0 ... the future of learning will be dramatically different, in school and throughout life. <https://www.peterfick.com/2017/01/future-education-young-everyone-taught-together/>. (blog January 24)
- Gajek A., Fabiano B., Laurent A., Jensen N., 2022, Process safety education of future employee 4.0 in Industry 4.0, *Journal of Loss Prevention in Process Industries*, 75, 104691.,
- Graham C., 2018, What is industry 4.0? Intelitek releases white paper on changing education system to prepare students for the demand of modern society and the industrial workspace, <https://www.intelitek.com/what-is-education-4.0>
- Haron H., 2018, Education in the era of IR 4.0, *International Conference on Information Management and Technology (ICIMTech)*, September 3-5, 2018, Jakarta, Indonesia, 1 - 35.
- Jamiesen M. V., Lefsrud L. M., Sattari F., Donald J., 2020, Engineering safety and risk management: a structured case study approach, *ASEE'S Virtual Conference, At home with engineering education*, June 22-24, 2020, paper ID#30956, 1 -24.
- Khan F., Amyotte P., Adedigba S., 2021, Process safety concerns in process safety digitalization, *Education for Chemical Engineers*, 34, 33 – 48.
- Kouwenhoven P., 2021, Process safety education: a comparative review, *Education for Chemical Engineers*, 36, 128-142.
- Laciok V., Bernik A., Lesnak M., 2020, Experimental implication of new technology into the area of teachingoccupational safety for industry 4.0, *10(3)*, 403 – 407.
- Laciok V., Sikorova K., Fabiano B., Bernatik A., 2021, Trends and opportunities of tertiary education in safety engineering moving towards Safety 4.0, *Sustainability* 2021, 13, 524.
- Pasman H.J., Fabiano B., 2021, Highlights and an impression of process safety evolutionary changes from the 1st to the 16th LPS present and future of the European loss prevention and safety promotion in the process industries. *Process Safety and Environmental Protection*, 147, 80-91.