Conceptualization of the Lecture 'Digitalization and Digital Transformation in Metal Forming' based on Implications from Contemporary Teaching and Learning Theories

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Abstract

In the modern world, the economy and society are affected by ongoing changes triggered by a multitude of influencing factors, e.g., digitalization, (g)localization, and global pandemics. Therefore, industrial engineering education needs to focus on the ongoing evaluation and the continuous development of new, respectively adapted, teaching and learning approaches to contribute to the continuous development of abilities, skills, and competences of the human workforce. Based on the implications of current teaching and learning theories, this paper focuses on the conceptualization of the lecture 'digitalization and digital transformation in metal forming'. As a result, the authors present a module-based structure that includes theoretical lectures, practical demonstrations, group discussions, and industrial case studies. The developed teaching and learning concept can be used as a reference guideline to contribute to professionalization and lifelong learning for the industrial engineering profession.

1 Introduction

Industry 4.0 approaches offer a multitude of new concepts and technologies to increase the competitiveness of manufacturing enterprises by relying on the basic principles of digital interconnectivity, autonomization, self-control of systems, and big-data analysis (Bosch et al., 2017; Woschank and Zsifkovits, 2021). Thereby, the usage of new technologies like artificial intelligence, machine learning, deep learning, as well as other IT-related innovations, will have a significant impact on the many fields of action within a manufacturing enterprise, e.g., on the strategic and tactical process optimization, cyber-physical systems, predictive maintenance, hybrid decision support systems, production planning and control systems, and the improvement of operational processes (Woschank et al., 2020).

In this context, the systematic evaluation of potential barriers and necessary requirements for a successful implementation of Industry 4.0 initiatives indicates a tremendous need for the realignment of current learning and teaching approaches in industrial engineering education (Dallasega et al., 2019; 2020; Woschank and Pacher, 2020).

Up to now, only a few studies have dealt with the design of new lectures based on empirically validated success factors for the further development of human skills and competences in the modern industrial environment. Additionally, current initiatives regarding the development of teaching and learning in industrial engineering education seem to ignore a multitude of potential exogenous and endogenous influencing factors in professionalization processes, leading to low efficiency in the proposed achievement of the established learning outcomes.

Therefore, this paper reflects current teaching and learning approaches that are applied to the new conception of the lecture ‘digitalization and digital transformation in metal forming’. The lecture will be further divided into four modules, ‘Module I: Digitalization – Theoretical Part’, ‘Module II: Digitalization – Practical Part’, ‘Module III: Digital Transformation – Theoretical Part’, ‘Module IV: Digital Transformation – Practical Part’ and contains a balanced mixture of theoretical lectures, practical demonstrations, group discussions, and industrial case studies by using a hybrid approach of both online and offline settings supported by state-of-the-art technology. Finally, the concept lecture can be seen as a starting point for the systematic development of competences regarding the areas of digitalization and digital transformation in metal-forming-related production systems.

2 Teaching and learning theory approaches

Learning can be defined as a lifelong process that is based on continuous reflection and change processes in confrontation with oneself and with the environment. Thereby, exemplary learning environments are work, education, leisure, further education, family, and friends. Learning takes place any in these learning environments or within the framework of transitions between them. In this context, the concept of lifelong learning (LLL) describes the necessity to learn during the entire life based on structured educational and learning processes, due to the ongoing changes in the knowledge society (keywords: industrialization 4.0, the half-life of knowledge, etc.) and the associated need for action. These targeted learning activities aim at the continuous improvement of subjective abilities, skills, and competences. The approach of LLL leads to a delimitation of learning and, thus, to massive changes at the institutional level. Accordingly, the pedagogical focus should not only be placed on the design of appropriate learning environments, but also on the creation of appropriate institutional frameworks. Thereby, the modularization of educational offerings can be regarded as one way to create flexibility and achieve the goals of LLL initiatives. In any case, networking and cooperation are essential on all levels. Educational institutions on various educational levels must be more closely coordinated to develop the so-called transversal competences. Also, the forms of learning must be expanded to include informal and non-formal learning processes. Thus, previous learning experiences must be interlinked with subsequent individual and organizational learning experiences. This should influence not only the micro-level, but also the meso- and macro-level of LLL (Hof, 2013). Moreover, the perception of transitions must be more strongly focused on both the individual and the institutional side. A precise framework of educational needs and educational necessities must be defined and, therefore, operationalized, on the institutional level, as well.

2.1 Teaching and learning processes in transitions

Due to the current characteristics of modern societies, the decoupling of standardized curricula vitae, flexibilization, and the focus on learning within the curriculum vitae becomes necessary. However, lifelong learning activities are not linear and continuous, thus they are determined by transitions, i.e., situations of upheaval or transitions with challenges for new- or re-learning. Transitions can be defined as social processes that enable changes in habits, patterns of action, and behavior (Felden, 2014). Particularly, in the current situation of social upheaval, every transition triggers subjective learning experiences and learning processes that transform the unknown into the known, and vice versa. In these transformations, not only is new knowledge acquired but also a new perception of the world is generated. In this context, Marotzki and Koller refer to the framework of ‘transformative educational processes’ (Hof, 2013). Mezirow further argues that, in line with the theoretical considerations of Habermas, learning always takes place through interaction and that, in the context of transformative learning processes, a reflexive discourse is needed as an essential dimension for achieving a mutual understanding and a change in subjective attitudes (Zeuner, 2014). Moreover, challenges in transitions require a closer look at learning and educational processes. In the sense of a phenomenological or socio-constructive view of learning, this can be generated by experiences, for example in the daily life. The social constructivist theory of learning assumes that learning interlinks new and existing experiences and then creates a subjective perception of the world that is determined by cultural, normative, and social interpretations. Accordingly, learning starts from the individual and subjective human experience within their ‘worlds of learning’ (Felden, 2014). The goal of the transformative learning approach is the individual as well as the collective development of the ability to act in the respective living environments, both from a social and a political perspective. This implies an ongoing change and/or further development of changes in all life situations.

Therefore, the current teaching and learning theory approaches and frameworks must be modified and/or extended according to the current trends described above to generate new strategies for action. For students and future experts, it is essential that the learning processes during the selected curricula are to be regarded as 'useful'. Accordingly, learning as a societal requirement further involves the removal of boundaries at all levels (e.g., forms of learning, places of learning, learning media, and learning times) (Maier-Gutheil, 2015). In this context, the implications of Woschank and Pacher (2020) will be used for the professional planning and monitoring of teaching and learning processes in the context of ILEE by developing a new conception of a lecture in the following chapter.

3 Lecture 'Digitalization and Digital Transformation in Metal Forming'

This lecture deals with the fundamentals of the fourth industrial revolution, under special consideration of issues regarding the metal forming industry. Especially in metal forming, which can mainly be divided into forging and sheet forming, specific issues arise when state-of-the-art holistic digitalization frameworks are applied. Complex processes, and, in general, a low degree of automation make it difficult to apply real-physical decoupled, data-driven digitalization solutions to this industry field. During research carried out at the Chair of Metal Forming at the Montanuniversitaet Leoben in 2019, the following concepts and key technologies were identified as an enabler for a successful digitalization and digital transformation in this industry segment: 1) Cyber Physical Production Systems (CPPS) with special focus on their Human Machine Interface (HMI) on the shop floor; 2) Industrial Internet of Things (IIoT), related transfer protocol technologies and corresponding IT-security approaches; 3) Finite Element based Digital Shadows (DS), Digital Twins (DT), and their connection to Artificial Intelligence (AI) and Big Data Applications; 4) Change Management, especially bottom-up commitment (Ralph and Stockinger, 2020; Zsifkovits and Woschank, 2019; Rauch et al., 2020).

3.1 Objectives

This lecture aims to get to know the potentials and challenges of the fourth industrial revolution in the field of metal forming. The theory learned is demonstrated using practical developments at the Chair of Metal Forming.

After successful completion of this lecture, students should be able:

- to create and evaluate concepts for the digitalization in metal-forming-related production systems
- to apply the theoretical concepts in the case study
- to apply and implement them together with experts from different disciplines
- to understand and implement the applied procedures in practice based on the theoretical and practical knowledge acquired

3.2 Main schedule and assessment

The lecture is characterized as an integrated lecture (IL) and will be supported by Moodle in a flipped classroom style. During the attendance times, the respective valid hygiene measures and guidelines are included in the execution. The lecture will be implemented in summer semester 2021 with a workload of 2.5 ECTS within the following timeline of the modules:

- Module I: February-March
- Module II: April
- Module III: May
- Module IV: May-June

3.3 Assessment criteria

Due to the focus on measurable and comparable learning outcomes, the 'learning outcome approach' was applied. According to Adam (2004), this approach includes "[…] what a learner is expected to know, understand and/or able to demonstrate at the end of a period of learning. They are usually defined in terms of a mixture of knowledge, skills, abilities, and understanding, that an individual will attain as a result of his or her successful engagement in a particular set of higher education experiences." The learning outcome orientation should aim at the quality development of educational measures as well as make learning outcomes visible and above all comparable. The challenge is "how learning outcomes can be systematically achieved, described, recorded, and compared" (Schlögl, 2012). According to this, however, learning outcomes can only be determined 'pragmatically', since both the learners and the teachers and the entire teaching and learning process influence the 'learning outcome' (Pacher, 2019). The more accurately these learning outcomes reflect real learning achievements, the greater the success (Zürcher, 2012).

Different measurement methods are used to evaluate the students' performance and are shown with percentages, as the following overview shows:

- Module I: Written exam, 60% of grade
- Module II: Cooperation during the practical demonstration, 5% of grade
- Module III: Contribution during the discussion, 5% of grade
- Module IV: Presentation, 30% of grade

The first module concludes with a written test to assess the students' theoretical knowledge. This basic knowledge is an essential prerequisite for the following modules and practical training. In further modules, the focus is also on cooperation and active participation in various practical training courses. Accordingly, the respective cooperation is documented by the lecturer throughout the lecture and then included in the overall evaluation. At the end of the lecture, the theoretical and practical contents worked out in the modules are presented to the plenum. The students have the task to present a strategy and an operational approach for a digitalization project.

3.4 Grading

The grading follows the following 5-part scale:

- Not sufficient (5); < 50%
- Sufficient (4); ≥50 - <62.5%
- Satisfactory (3); ≥62.5 % - <75%
- Good (2); ≥75% - <87.5%
- Excellent (1); ≥87.5%

3.5 A generic overview of the structure

This lecture will be mainly divided into four parts: 1) Theory of fundamentals in digitalization: A face-to-face introduction in the lecture structure followed by Moodle supported self-study of the theory; 2) Practical demonstration on digitization and digitalization technologies at the Smart Forming Lab at the Chair of Metal Forming (Ralph et al., 2020); 3) Digital transformation in metal forming: Face-to-face discussion of practical issues regarding implementation of digitalization technologies in the metal forming industry (Change Management); 4) Case study about a typical digitalization project in the industrial environment.

3.5.1 Module I: Digitalization – Theoretical Part

As depicted in Table 1, the first part of this lecture will mainly be taught via e-learning powered by Moodle. The most important approaches and key technologies of digitalization in the metal forming sector are included and will be provided via four digital chapters. Students can learn independently. To give all participants an appropriate framework, each sector of this module starts with the learning objectives, which should be achieved after the complete elaboration of the provided course material. Due to the lack of homogeneity in academic literature, prepared scripts for content (2), (4), and (5) will be provided. Furthermore, the most important state-of-the-art academic research papers will be accessible. For students who want to deepen their knowledge in specific areas of module I, additional book chapters will be provided. At the end of each section, possible exam questions related to the scope of the specific part will be visible, which should support every student in their exam preparation and avoid misunderstandings regarding the scope of the exam. Additionally, at least two questioning hours will be provided to support students during the preparation process.
At the end of module I, a written exam will take place. This exam is crucial, as a minimum of knowledge in theory and nomenclature is necessary to be able to understand the upcoming modules of this lecture and contributes 60% to the final grade.

Table 1. Module I: Digitalization – Theoretical Part.

<table>
<tr><td colspan="2">Module I: Digitalization –Theoretical Part:
Face-to-face and online</td><td colspan="2">Timeframe: 4x1h, 2x2h, 1x3h, 1x6h, 1x15h</td></tr>
<tr><td colspan="4">Topic(s): Introduction and arising of awareness for chances and issues of digitalization in the metal forming industry (1); Fundamentals of automation in the metal processing industry, including retrofitting and digitization (2); Fundamentals of networking technologies: state-of-the-art protocols and data management, including retrofitting and IT-security (3); CPPS and HMI in the metal forming environment (4); DT and DS in metal forming related operations, including AI and big data (5)</td></tr>
<tr><td colspan="4">Objective(s): Knowing the most important definitions and differences in metal forming related digitalization key technologies; Raising the ability to communicate with IT-domain experts in the manufacturing environment; Understand the possible advantages of digitalization technologies</td></tr>
<tr><td>Content:</td><td>Methods:</td><td>Material:</td><td>Duration:</td></tr>
<tr><td>(1)</td><td>Face-to-face lecture;
group discussion</td><td>PPT; handouts; videos</td><td>1h</td></tr>
<tr><td>(2)</td><td>Moodle-based e-learning; online script;
actual research papers; videos</td><td>PDFs; videos</td><td>2h</td></tr>
<tr><td>(3)</td><td>Moodle-based e-learning; actual research papers; videos; practical tutorials</td><td>Online tutorials; PDFs; videos</td><td>2h</td></tr>
<tr><td>(4)</td><td>Moodle-based e-learning; online script;
actual research papers; videos</td><td>PDFs; videos</td><td>1h</td></tr>
<tr><td>(5)</td><td>Moodle-based e-learning; online script;
actual research papers; videos</td><td>PDFs; Handouts; videos</td><td>3h</td></tr>
<tr><td colspan="4">Remarks: Additional case studies for deepening of gained knowledge provided at Moodle, including additional book (chapter) recommendations (6h); Exam preparation: Predefined possible exam questions for elaboration, published via Moodle (15 h); Written exam to demonstrate necessary knowledge for the upcoming practical part (1h); Total 60% of the final grade</td></tr>
</table>

3.5.2 Module II: Digitalization – Practical Part

Table 2 displays the concept of the second module which is used to deepen the theoretical knowledge gained in module I. A division in an equally sized group of eight will be carried out in the first instance. Every group will then attend three practical units at the Smart Forming Lab at the Chair of Metal Forming. Parts (1) and (3) will include face-to-face lectures and rely heavily on interest-driven group discussion. In part (2) of this module, every group will additionally program its methods in Python, which then will be transferred into the four-layer digitalization architecture at the lab. The cooperation of each participant during the parts will contribute five percent to the final grade of this lecture. The contribution will be measured inversely. Initially, every student will start with a full five percent, students who show no effort in contributing productively or disturb the workflow or group discussion inappropriately will be graded with zero percent for this module.

Table 2. Module II: Digitalization – Practical Part.

<table>
<tr><td colspan="2">Module II: Digitalization – Practical Part:
Face-to-face</td><td colspan="2">Timeframe: 1x1h, 1x2h, 1x3h</td></tr>
<tr><td colspan="4">Topic(s): Explanation and practical demonstration of the fundamentals of automation and networking technologies via a four-layer digitalization approach, including DS, DT, and AI (1); Practical demonstration of a suitable implementation approach for CPPS and HMI, demonstrated by the Chairs retrofitted experimental cold rolling mill, using a variety of different software (2); Showing practical open-source IIoT solutions, demonstrated on operating machine hour counters and related project management implementations at different forming aggregates (3)</td></tr>
<tr><td colspan="4">Objective(s): Knowledge transaction from theory into practical implementation; Deepening the understanding to know the fundamentals of digitalization as a future domain expert</td></tr>
<tr><td>Content:</td><td>Methods:</td><td>Material:</td><td>Duration:</td></tr>
<tr><td>(1)</td><td>Face-to-face lecture;
group discussion</td><td>Different forming aggregates and infrastructure at the Smart Forming Lab</td><td>3h</td></tr>
<tr><td>(2)</td><td>Face-to-face lecture; group work;
group discussion</td><td>Demonstrating the digitalization environment of the Smart Forming Lab, including cold milling aggregate and different software</td><td>2h</td></tr>
<tr><td>(3)</td><td>Face-to-face lecture;
group discussion</td><td>Showing the four-layer architecture and the advantages in digitalized project management by using the Smart Forming Lab</td><td>1h</td></tr>
<tr><td colspan="4">Remarks: Total 5% of the final grade</td></tr>
</table>

3.5.3 Module III: Digital Transformation – Theoretical Part

As outlined in Table 3, the third module deals with the specific issues related to the implementation of digitalization technologies as part of a digital transformation framework in the metal forming environment. During a two-hour face-to-face meeting, the participants should realize the importance of corporate culture and human coworkers as part of the digital transformation process. This knowledge will be gained through practical case studies related to change management and metal forming related companies. To be able to use the gained knowledge through the practical examples given in part (2) and (3), in the first instance, a theoretical background about the fundamentals of corporate culture and change management will be provided. This part will contribute five percent to the final grade and grading will be underlying the same restrictions as in module II.

Table 3. Module III: Digital Transformation – Theoretical Part.

<table>
<tr><td colspan="2">Module III: Digital Transformation – Theoretical
Part: Face-to-face</td><td colspan="2">Timeframe: 1x2h</td></tr>
<tr><td colspan="4">Topics: Major issues regarding the implementation of digitalization technologies in the metal forming environment (1); The importance of top-down and bottom-up change management (2); Practical change management approaches in the metal forming industry (3)</td></tr>
<tr><td colspan="4">Objective(s): Understanding the fundamentals and purpose of change management in metal processing manufacturing; Generating awareness for the most important challenges arising with digital transformation on the different layers of management; Knowledge about practical approaches to overcome the most common resistance in a sustainable way</td></tr>
<tr><td>Content:</td><td>Methods:</td><td>Material:</td><td>Duration:</td></tr>
<tr><td>(1)</td><td>Face-to-face lecture;</td><td>PPT; board</td><td>1h</td></tr>
<tr><td>(2)</td><td>Interactive face-to-face lecture;
group discussion</td><td>PPT; board</td><td>0.5h</td></tr>
<tr><td>(3)</td><td>Interactive face-to-face lecture;
group discussion</td><td>Board</td><td>0.5h</td></tr>
<tr><td colspan="4">Remarks:</td></tr>
</table>

3.5.4 Module IV: Digital transformation – practical part

Table 4 provides information about the fourth and final module of this lecture. This module will summarize the theoretical and practical inputs participants acquired during the lecture. Each group, as defined in module II, has to elaborate on a different case study. The scope of the studies will be the implementation of a specific digitalization technology in a fictive metal forming company, under special consideration of issues regarding the digital transformation strategy to achieve the primary goal. The variation of at least one factor (e.g., company size, budget, degree of automation) will be carried out to avoid the same results from more than one group. The individual solution of each group will then be assessed by a short presentation (maximum 10 minutes), considering the solution provided as well as the presentation style. This module has an estimated workload of 22.5 hours and contributes to the final grade with 30 percent.

Table 4. Module IV: Digital Transformation – Practical Part.

Module IV: Digital Transformation – Practical Part: Face-to-face		Timeframe: 1x20h, 1x2.5h	
Topics: Developing a strategy and operational approach to successfully run a digitalization project (1); Summarizing and presenting the elaborated solution in an appropriate way (2)			
Objective(s): Participants can run a digitalization project in the metal forming industry successful			
Content:	Methods:	Material:	Duration:
(1)	E-learning, group work	Lecture material	20h
(2)	Presentation	PPT; board; video	2.5h
Remarks:			

4 Conclusion

In summary, it can be stated that, in the future, a major focus in the formal education and training sector should be placed on improving quality assurance and on professionalization processes. Hereby, the main goal is to strengthen the individual position and competence to contribute to the professionalization of the entire sector and to establish the engineering profession as an essentially necessary component in the sense of the demand for lifelong learning (LLL). In addition to the development of individual professionalism, collective professionalism development must also be promoted by implementing standardized frameworks and pre-defined procedures.

Based on current teaching and learning theories, this paper has introduced a module-based concept for the lecture 'digitalization and digital transformation in metal forming' as an example for modern industrial engineering education. Thereby, the authors placed a special emphasis on current Industry 4.0-requirements of manufacturing companies by focusing on the usage of modern technologies such as cyber-physical production systems, the Industrial Internet of Things, human-machine interfaces, and augmented reality. To guarantee an efficient knowledge transfer, the students will be actively involved during the lecture through participant-based teaching and learning methods, e.g., group discussions or industrial case studies.

Future research should further focus on the systematic evaluation regarding the impact of potential success factors of modern teaching and learning methods on learning outcomes by using multivariate statistical procedures. Moreover, the gap between offered and required educational services should be further reduced by incorporating recent scientific findings as well as company-orientated requirements into the educational programs of future industrial engineering education.

5 Acknowledgments

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7 Biographies

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Corina Pacher is an Education Project Manager at the Resources Innovation Center in Leoben. She studied pedagogical and educational science at the University of Klagenfurt with a specialization on social and inclusive education as well as on professional education. During and after her studies, she gained work experience, e.g., as the head of educational programs and in different social public service enterprises as social education worker. Currently, she is mainly focusing on raising the awareness for a resource-orientated handling of raw materials by connecting research, education, and society, e.g., by building and expanding skills and competences of students through training initiatives.