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Development of a digital learning platform for the planning of manufacturing processes

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Abstract. The planning of manufacturing processes is an important part of the work of engineers and skilled workers. Students of engineering sciences and apprentices come with too little practical experience in studying and training, in the study and/or training period valuable competencies at machines and mechanisms often cannot be acquired. The use of a digital learning platform to convey such content can help to develop the needed competencies among the target groups. The aim of the paper is to describe the concept and a pilot system for a learning platform. A cross-border project between partners from Germany and Czech Republic develops a concept for a digital learning platform and a pilot system. Daily practice of work process studies flows into the design of the platform with realistic workpieces, processes, procedures and systems. A wide range of media is provided: texts, audiovisual sequences, simulations. They support the mental integration of the contexts. Learning and working tasks at various stages of difficulty support the development of student’s and apprentice’s skills. The implementation of the recorded aspects in the form of a pilot solution was extensively tested with the target groups. The experiences and feedback provide a valuable basis for improving the overall concept.

1. Introduction
Manufacturing companies in Germany and the Czech Republic are producing products of high quality for different applications. This is needed in order to convince in international competition with other countries in the European Union and all over the world. The upcoming structural change with the growing requirements from the implementation of the Industry 4.0 strategy has to be taken into account. With this development at the centre of innovative production systems there is a need for qualified specialists. The training of engineers and skilled workers needs to take greater account of these future requirements. Both groups not only need knowledge about manufacturing processes but also have to build up competencies in order to cope with the growing complexity of automated production in the future. Therefore, it is needed that engineers and skilled workers are able to know and master all required steps during the planning and manufacturing of components.

This requires professional-technical planning skills in:
  • manufacturing process elaboration - the steps from the blank to the finished part (as operations along various production stations or machines)
• understanding and shaping of operations on each machine (especially the machining) with its parameters, and
• planning the production management at various production stations on a shopfloor and check a.w.a. ensure the availability of the machines.

2. Empirical studies
At the beginning of the project the following questions had to be answered: Which competences concerning production planning and control should be acquired by the learners at Saxon and Czech universities and vocational schools? What difficulties can be identified in university courses as well as in vocational classes on production planning and control? Which aspects of production planning and control can be found in typical work processes of the target groups?

Inquiries were carried out to answer these questions: curricula-analyses of university courses in mechanical engineering and cutting mechanic-related occupations in Germany and the Czech Republic should show the development of relevant competences. Deficit analyses should show the existing weaknesses, difficulties and problems at universities and vocational schools in both countries concerning learning the contents of production planning and control. In work process analyses, production orders and manufacturing assignments were explored with regard to the competence requirements for engineers and skilled workers. For reasons of space, in particular the results of the deficit and work process analyses are discussed here.

2.1 Results of deficit analyses
In the core, here the question was asked which problems teachers at universities and vocational schools see in the understanding of learners in the areas of production planning and control of machining processes.

At vocational schools in Saxony, it often happens that learners arrange the steps of a manufacturing process in incorrect order (e.g. tapping before core hole boring) - apparently there exists a lack of clarity in technological contexts. There is also a need to catch up in competences in the handling of clamping devices. Problems in understanding also arise if some learners are unfamiliar with certain tools, clamping devices or machining processes from their practical experience in the companies. As a consequence of these deficits, teachers state that frustration and resignation sometimes occur among learners. In the Czech vocational schools which were examined, detailed deficits could not be identified – rather, it was found that production planning and control generally seem to appear only marginally.

At the universities which were examined, reasons for deficits emerge that partly lead directly and indirectly to a more or less poor development of relevant competences. As an indirect cause, it is said that students sometimes can read and understand technical drawings only insufficiently (imagination of the workpiece to be produced; understanding of the coded information in drawing elements, letters and numbers etc.). This results in wrong or incomplete steps in the solution of the manufacturing tasks. A direct cause is that it is difficult to select specific manufacturing processes due to insufficiently studied basic subjects (such as manufacturing and materials technology) and their application as transferable knowledge. In addition, there are problems with the correct arrangement of operations and process steps in the manufacturing process as well as with the structure of process sequences in the form of “one-option” or “more-option” process graphs in general. Finding suitable strategies for clamping and reclamping of workpieces represents further difficulties. It is also suspected here that there is a lack of competence in reading technical drawings in order to identify suitable clamping surfaces and that the provision of courses on clamping technology- contents in general is too small.

2.2 Results of work process analyses
In both countries, work process studies were carried out for engineers in work preparation departments and for skilled workers on the shop floor. The overall objective was to find out to what extent the employees in the work preparation departments and on the shop floor are involved in the planning and control of production orders and what skills are required for this. Most of the companies came from the sectors of toolmaking and small and medium series parts manufacturing.
The participation of skilled workers in production planning and control varied among companies. In the case of less complex single parts, the skilled worker generated the NC code on the machine for the workpieces independently (determining the operations; defining clamping devices and tools as well as clamping situations and other manufacturing parameters). Then the machine setup was done and the batch was manufactured, including monitoring. The skilled workers often operated several machines at the same time, usually with two to three workpieces in average. The production control was also sometimes (co-)conducted by the skilled workers, for example, when different manufacturing assignments were collected on one machine for reasons of rationality, or when assignments were brought forward or backward due to prioritization.

The engineers in the work preparation department usually received a 3D data set of the workpiece to be produced from the design department or directly from the customer. Then an analysis was carried out on the computer with regard to workpiece size, quantity, tolerance specifications, difficult geometries and general technical feasibility. Resource planning systems (ERP systems) were used to plan and control production, importing data from calculation programs. When determining the raw part, either an ordinary semi-finished product from in-house was used or purchased from external suppliers. Another way was rather “pragmatic”: The employer in the work preparation department enclosed the workpiece by a bounding cube and added material on all sides. Than the “finished” blank was ordered directly from the material supplier. If manufacturing operations were not specified by the customer, these had to be determined. Then concrete machines were selected from the machine pool. At the same time, orders were placed for external services (e.g. electropolishing, deep hole drilling or welding and grinding processes). In some cases, close cooperation with colleagues from the programming department was necessary. The next step was to plan the realization of manufacturing processes on the shopfloor – or more specific: when has which operation to be carried out on the workpiece? On the basis of calculated times and available capacities, the throughput was determined for each manufacturing area (e.g. turning, drilling, milling etc.). On the shopfloor, the foreman then took over the data for the fine control (which operator on which machine).

3. Concept for a digital learning platform

Learning with digital media is considered to have a high educational potential [1], [2] and [3]. Learning platforms as web-based teaching and learning systems offer numerous functionalities for the organization and design of teaching and training at the places of learning and studying. In addition, they can provide tasks and many different learning materials and media for solving learning tasks. Moreover, there are opportunities for the mutual exchange of learners for joint action [4] and [5].

3.1 Functionality of the learning platform

The platform, which is available in German, Czech and English language, is intended to provide learning and working tasks with different degrees of self-direction and support at different levels for application. At level 1, in addition to get familiar with the learning platform, the main objective is to understand suitable approaches and appropriate solutions for the planning of manufacturing processes for concrete workpieces. There, the learners are to be guided strongly through the learning platform and the decisions to be made by the learners are of quite low complexity. At level two, self-direction increases to the extent that the students select possibilities from a limited number of solution. The guidance through the learning platform is supposed to be considerably lower here. At the same time, the feedback function should provide information for the learners on the suitability of their selection concerning suitable clamping devices, tools or manufacturing parameters. Little assistance, e.g. in the form of texts, video sequences or simulations, support the learners in their planning work a.w.a. in necessary corrections or adjustments. At the third stage, the learners will work out a solution completely independently - a given number of solution will then no longer exist. A feedback function provided by the learning platform will then be replaced at this level by feedback from a teacher due to the “endless” number of possible solutions the learners can create principally. However, this does not affect the possibilities of support through various media provision. This range of functions should be available at the end of the project.
For the proof of the concept, at first a pilot solution was developed. The following illustrations show the current work status of the user interfaces for each of the three parts / modules of production planning and control (manufacturing process planning – figure 1, manufacturing process elaboration - figure 2 and production control - figure 3).

**Figure 1.** User interface manufacturing process planning.

**Figure 2.** User interface manufacturing process elaboration.

**Figure 3.** User interface production control.
Learning and working tasks with increasing degrees of difficulty will be placed on each level. Both the complexity of the workpieces may increase (e.g. due to more demanding form elements, cf. figure 4) and the manufacturing assignments may become more challenging (single part versus small series versus mass production) or the frame conditions of the production tasks may change (e.g. through specification of unavailable machines due to unexpected utilization or breakdown). There are thus numerous dimensions that will offer scope for variation in the demands placed on learners. Up to now, the learning platform has not included aspects of company organization, which were explored in the work process studies. The integration of these aspects will be an important task in next project steps.

![Figure 4. Increased complexity of the form elements on the workpieces.](image)

From perspective of teaching and learning, the most important components of the platform are doubtless the provisions and functions to support learning. In addition to feedback functions for decisions that have been made by the learner, the main focus here is on the media to be integrated. In the project POKROK.digital the integration of appropriate media will be achieved in at least two ways:

- Firstly, work environments close to the workplace, such as production facilities or machine halls, are designed and programmed in the same way as they occur in reality (cf. figure 3). Similar to serious games, workers can be moved in a targeted manner and workpieces, machines and tools can also be used in a variety of ways (virtual operation of the machine) as they are virtually available as 3D models.
- Secondly, it is necessary to integrate media that provide explanations and contextual knowledge, illustrate cause-and-effect relationships and facilitate the development of findings. In addition to classical texts, the focus here is on simulations of processes and, in particular, film sequences produced with high-speed or thermal cameras, which increase the clarity of certain facts.

### 3.2 Integration of expertise from three subjects

The structure and design of the learning platform in the POKROK.digital project requires considerations from three closely connected areas:

The main focus of vocational pedagogical and didactical considerations is the generation of suitable learning and working tasks that specifically pick up the findings of the work process analyses, like working subject of engineers and skilled workers activity; used tools, machines and devices; aspects of cooperation etc. The starting points are the results from the curriculum analyses with regard to competence development objectives in the field of production planning and control (which competencies of engineers or skilled workers are relevant to solve the respective manufacturing planning tasks?). It will be a future duty to improve and extent the already existing learning and working tasks with particular view on the needs of the students both at universities and vocational schools as well as
the project-based features learning and working tasks usually have. Further didactic considerations must be made on the suitability of workpieces whose production has to be planned. Moreover the type and scope of learning support at the various levels has to be taken in account. Last but not least, appropriate and purposeful forms of feedback for the learners through the learning platform and suitable media (texts, simulations, audio-visual media) are to be developed which support the understanding and the learning processes of the students.

From a technical-technological perspective, technological project staff, in consultation with project partners of didactics, first had to select and provide suitable workpieces. The engineering project staff from Dresden and Freiberg then created the corresponding plans for the selected (and suitable regarded) workpieces - both for the entire production process and for each single process steps. From these plans, the information required for manufacturing on machines, tools, clamping devices, parameters, etc. was derived. For the control of production, up to now it was necessary (and will be further) to design and program suitable workshops and production facilities. The project partners of TU Liberec were responsible for this work. The technical-technological contents are realized by three modules (manufacturing process planning, manufacturing process elaboration, production control).

Information-technological considerations firstly focus on the entirety of all technical-technological processes. The three modules form a unit, having a uniform data structure and a common user interface. The 3D models of the tools and machines as well as the associated animations are also the work results of the project partners in Dresden and Freiberg. Last but not least, this comprises the integration and activation of learning media, which include film sequences of the real machining of the workpieces contained in the work tasks. The latter were produced by project staff from Dresden and Usti nad Labem.

In addition, simulations of machining and acting of skilled workers were integrated, created by project partners of TU Liberec (cf. figure 3).

4. Conclusion and outlook

The development of a learning platform that deals with the planning of production processes is a challenging project. After almost 2 years of project duration, the empirical analyses have created important starting points for the targeted development of learning platforms and tasks. In recent months, the focus has been on the development of an initial test version, which started to be tested in vocational and higher education institutions. The evaluation will focus on teachers and learners. For the latter, testing results should provide information on the usability aspects and the extent to which the learning platform is perceived as helpful or supportive. Teachers will be asked to what extent they estimate the use of the learning platform helpful and beneficial and what limits they see in this context. The results of this test or evaluation phase then form the basis for improvements, optimisations and extensions.

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