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DEVELOPMENT OF USER GROUP SPECIFIC TRAINING CONCEPTS FOR METROLOGY IN INDUSTRIAL APPLICATION

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Abstract – Measurement results provide important information about the measured objects. In industrial application, this is used to inspect products and control processes. To enable reliable statements based on the measurement results, all concerned employees need sufficient competences to fulfil their specific tasks, e.g. a correct execution of the measurement task, but also a proper interpretation of measurement results or inspection-oriented and functional dimensioning.

So far, many training offers for operators in metrology have been developed. But other user groups in an industrial enterprise also need appropriate training regarding fundamental knowledge and a basic understanding for metrological concerns. Thus, specific offers have to be designed, directed at the particular needs of typical user groups in an industrial enterprise, in order to enable informed communication and support cooperation among all employees concerned with the application of measurement results.

To ensure an efficient and comprehensive approach, a methodology for the development of advanced vocational training has been defined. Following this, a systematic analysis of the metrological competences needed by each user group has been executed. Combined with the results of a user needs analysis, requirements and constraints are defined as a base for the development of user group specific training concepts.

Keywords: advanced vocational training, manufacturing metrology, course development

1. INTRODUCTION

In industrial manufacturing, measurement results provide an indispensible source of information to assess the conformity of products and processes with given specifications and to thus assure their quality. In order to take well-funded decisions regarding production control or final release of goods to be delivered, reliable and reproducible measurement results are necessary. Here, competence and diligence of the metrologist may have a significant influence on the gathered result [1]. Therefore, over the last years a variety of training offers for the impartment of required fundamental skills and knowledge and diverse tools to support the correct execution of a measurement task have been developed (e.g. [2] - [8] and many others), amending courses by manufacturers of measurement devices which usually focus on handling, programming and maintaining the actual machine.

Yet, the performance of the measurement itself may not be seen as an isolated task. Quite the contrary, the measurement results themselves are worthless, if they are not interpreted correctly or if the measured features do not describe the intended properties of the object. Unfortunately, quality inspection is rarely considered as a regular step in manufacturing process chain, but rather as a merely supportive function. This easily results in an insufficient recognition of metrological concerns, regarding product development, design of manufacturing and purchasing processes or allocation of funds for investment. Finally, such underestimation of contribution will result in disadvantages for the enterprise.

Thus, employees in manufacturing metrology or quality inspection have to realise their function as an interfacial area of work and have to keep in close communication with connected departments of the enterprise. For an efficient cooperation, all involved groups need sufficient knowledge about each others' tasks to mutually understand existing concerns. Therefore, regarding training offers in metrology, the focus has to be opened up from the correct performance of measurement tasks to metrology-related functions in connected professional areas. Adequate training concepts have to be developed to impart required competences according to the specific demands of different target groups in an industrial enterprise.

2. METHODOLOGY FOR DEVELOPMENT OF ADVANCED VOCATIONAL TRAINING

In order to reach this aim with optimal result, it is useful to set up a methodological workflow. An efficient and comprehensive methodology enhances a broad analysis of the users' needs and thus supports achieving a training concept optimized towards the specific requirements and demands. Especially for teaching-learning processes it is important to consider the requirements of the intended target group in a holistic way, regarding content and established method as well as influences of the learner's surrounding

and the intended application of imparted knowledge. Also, a structured approach helps to detect subsurfaced constraints, which otherwise result in predeterminations limiting the scope of solutions and thus leading to suboptimal results.

For the development of basic educational offers, a seven phased scheme is widely used [9]:

1. Definition of learning objectives for the considered educational module
2. Analysis of target group
3. Conceptualisation of learning offer or class
4. Design of measure
5. Elaboration of educational material
6. Application of educational unit
7. Evaluation

The main structure of this methodology can be adopted to support the development of advanced vocational offers. Yet, it is necessary to establish an additional phase before the actual start to analyse the required competencies for a specific task. Out of this analysis, learning objectives can be defined. For primary education, this analysis is not compulsory, as learning objectives are derived from super-ordinate schedules, e.g. curricula, or are selected by a teacher or instructor who is commonly expected to have superior knowledge about a certain area and thus is able to specify the learning objectives adequately.

Also, it is necessary to include the special consideration of connection with and relation to practical application. For a primary education, it is evident that learning will be the main activity and that a long term use of the knowledge is required, whereas an immediate use is less important. For advanced vocational training, theses two conditions are not met. Thus, it has to be diligently considered which relation between work and learning would be advisable, considering especially scheduling of times and providing of information towards immediate use respectively long term improvement and sustainable learning.

Therefore, a comprehensive methodology for the development of educational offers for advanced vocational training has been designed (Fig. 1). Based on this methodology, training concepts for the user group specific impartment of metrology-related competences are developed.

3. ANALYSIS OF GROUP-SPECIFIC NEED OF COMPETENCES IN METROLOGY

For a system-oriented analysis of the needed competences, it has to be analysed which activities are performed by specific user groups in an industrial enterprise and which relation to manufacturing metrology exists. It is necessary to identify existing groups of users considering functional aspects. As each enterprise is organised in a singular way, there will be differences regarding the exact distribution of tasks among the user groups. Yet, it is possible to divide the employees in generic user groups mirroring typical contents of work. Based on this categorisation, concepts can be developed. Regarding the actual implementation in a specific company, it is easily possible to recombine the used elements according to the specific situation.

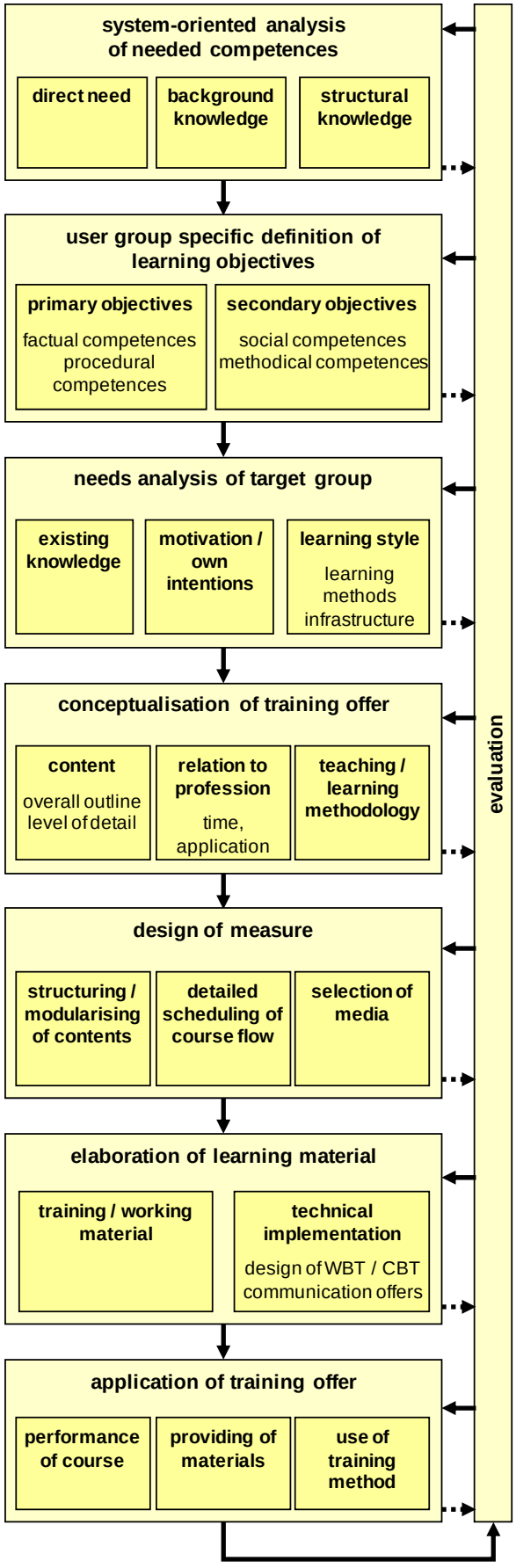

Fig. 1. Methodology for the development of measures for advanced vocational training.

3.1 Structure of user groups in industrial enterprises

The analysis of user groups is conducted based on the construct of Porter's value chain (Fig. 2) [10]. In the value chain, strategically important, independent and consecutive activities in an enterprise are visualized. Primary activities contain a direct use for the customer, whereas support activities provide necessary basics for the execution of primary activities. The process results in the manufactured product providing an economical benefit for the company.

Originally the construct of value chain is intended to enable the identification of potentials for economical optimisation. The profitability of each of the contained activities may be assessed by comparison with a benchmark partner, e.g. the reference market leader.

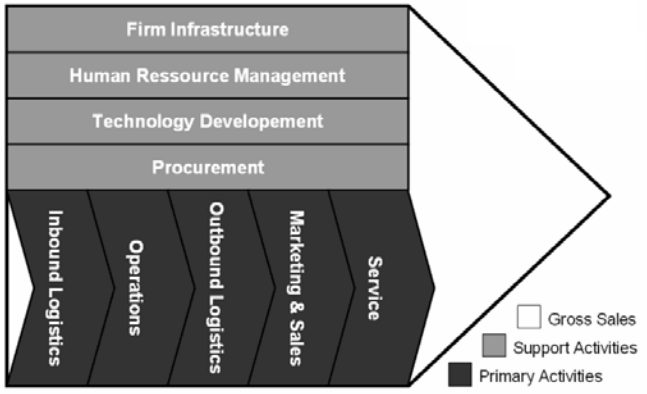

Fig. 2. The value chain [10]

Thus, the activities are classified in a way that enables a high comparability and transferability between individual enterprises and can be used as a base for the system-oriented analysis of required competences.

3.2 Group specific need of competences in metrology

The first primary activity, inbound logistics, contains the receiving of goods. To assure a sufficient quality of the purchased materials, adequate inspection is necessary. Thus, competences for the planning, execution and interpretation of acceptance inspections for all relevant measurands are necessary. It can be differed by hierarchical level between the mere execution of a fixed inspection processes and the definition of such processes. Also, competences in analysing measurement results and strategies are necessary in order to identify underlying reasons for differing results between own measurements and supplier documentation.

Operations, the second primary activity, cover the various processes of transforming input material to output products. Here, information about the quality of manufactured products and the underlying processes are necessary. Thus, competences for initial sample inspection and in-process quality control are necessary, containing planning, execution and interpretation of adept measurements. Especially, knowledge about the reasonable inclusion of quality control in the process is necessary. Here too, hierarchical levels can be differed considering the complexity and amount of the executed tasks.

Outbound logistics is due to deliver the manufactured products to customers. Here, final clearance has to be given for the products. Thus, competences are necessary to prepare and perform the measurement and compare results with the customer, if any differences occur.

Marketing and sales is oriented toward attracting customers for the products. Employees here do not need metrological skills but should know about the quality politics of their enterprise.

The last step of primary activities is service, covering all activities to conserve or augment the value of the product for the customer. Metrological competences are on one hand necessary to inspect broken parts in order to enable a feedback for the improvement of production processes. On the other hand given measurement results of final clearance by the own company or acceptance inspection by the customer have to be compared and interpreted.

Regarding support activities, in technology development metrological competences are needed to enable inspection-oriented dimensioning during development and construction of new products. For this, fundamental knowledge about different methods of inspection as well as specific knowledge about minimum tolerances to be inspected reliably in the company are required.

Employees in human resource management, procurement and firm infrastructure do not need special competences about metrology. Yet, it is very important to assure the appreciation of impact on the company's success gathered by quality control and metrology. Otherwise, strategic decisions regarding infrastructure, investments, employing of qualified workers and purchase of required measuring devices will not sufficiently consider the demands of metrology as it is only seen as a factor of cost.

Summarising, four main groups of employees may be differed regarding their concern with metrological subjects:

- *Metrologists or quality supervisors* who actively plan or execute measurement tasks on incoming, produced, outgoing or reclaimed products. This group additionally can be subdivided by the complexity or specialisation of executed tasks.
- *Contact persons in inbound or outbound logistics* or service who do not actively perform measurements but have to be able to interpret measurement results and identify possible reasons for differing results between customer and supplier.
- *Constructing and process planning engineers* in operations or technology development who have to know about the requirements of product inspection, their impact on product and process design and the available possibilities.
- *Other employees*, e.g. in sales, infrastructure or human resource management, who do not need specific metrological knowledge or skills, but a general idea and according appreciation of the impact, that metrological activities of the above mentioned groups have on the success of the company. This requirement for mutual appreciation between different sections of work also holds true for all other areas of activity in a company. Thus, there is no need for a special metrological training concept but rather for an adept overall philosophy.

4. DEFINITION OF LEARNING OBJECTIVES

For each of these four groups, specific learning objectives can be defined, covering the competences required for the execution of their tasks. These objectives have to be divided in primary objectives, covering factual and procedural competences, and secondary objectives, covering methodical and social competences. Regarding the primary objectives, strong differences exist between the different user groups, resulting from their specific set of tasks:

- *Metrologists or quality supervisors* shall be able to plan, perform and evaluate complex measurements. For this, they need broad factual knowledge about measuring principles of their machines, typical influences on the measurement and ways to reduce the impact of these influences, as well as basics about other measurement devices and principles and the ability to compare the different alternatives. This knowledge has to be based on a solid understanding of metrological fundamentals, such as mathematics, physics or product specification, and amending knowledge about the handling of measurement uncertainty or the principles of quality techniques. Also, they need the procedural competence to actually use this knowledge for the proper performance of their tasks. Generally, it is desirable that a metrologist has at least factual competences exceeding his current tasks. This enables a higher flexibility.
- *Contact persons in inbound or outbound logistics* need a profound factual knowledge about measuring principles and influences on measurements for all measuring devices used in the company. As for metrologists, this has to be supported by understanding of fundamentals and detailed information about the interpretation of measuring results and the further evaluation in quality techniques. Yet, regarding procedural knowledge, this group only has to perform interpretations and comparisons of different measurement results or strategies.
- *Constructing and process planning engineers* need mainly factual competences covering the requirements for measuring with devices available in the company and detailed knowledge about the interpretation of geometrical product specifications and their relation with functional properties of a workpiece. Regarding procedural knowledge, they need the ability to transfer these abstract concepts to actual product or process development.
- *Other employees* do not need any specific metrology related factual or procedural competences.

Methodical and social competences, the secondary objectives, are not focussed on a special task, but can be considered as basic requirements for the efficient application of factual and procedural competences. For the performance of measurements or the interpretation of measurement results, as a methodical competence especially diligent and self-controlled working is required, as a social competence the ability to consider connections to other working steps beyond the own responsibility and to take these further requirements into account for the own performance.

Mostly, the impartment of these abilities is rather not considered as an objective for task-oriented further vocational training. It is expected that employees have achieved the required competences mainly during primary education and can enhance them during special seminars focused on these “soft skills” [11]. Nevertheless, learning is always a social process and every training will have an impact on social and methodical competences as well by way of the so-called “hidden curriculum” [12]. Therefore, it is necessary to consider the desired secondary objectives during the definition of a learning concept.

5. ANALYSIS OF TARGET GROUPS

For the definition of concrete learning contents for an educational concept, the intended competences of the identified three relevant groups have to be compared with skills and knowledge expectable based on typical qualification profiles. Thus, a base of existing knowledge can be identified as a starting point for the learning concept and the demand for qualification can be subdivided in three categories:

- Impartment of new competences
- Broadening or deepening of existing knowledge for transfer to new areas of application
- Reactivating competences in order to avoid inert knowledge and maintain applicability.

Also, constraints for methods of teaching and learning have to be analysed in order to prepare a course adapted to the preferred learning style, thus enabling an efficient impartment of knowledge.

5.1 Design of user needs analysis

The employees of the mentioned groups typically differ widely regarding basic vocational qualification and professional experience. Thus, it is not recommendable to define the expected state of existing metrological competences based on an analysis of contents in basic vocational education. Complementarily, a survey of the intended target groups has to be conducted. On the one hand the level of competences commonly to be expected can be determined together with a measure of its usual variation, on the other hand the results of the conducted analysis can be verified. Comparing the results of this survey with the analysis of required competences, learning content can be defined for the identified groups. Additionally, requirements and demands of the users can be collected regarding adequate learning methods to be implemented, available time and resources for training and already existing measures of the company to impart the required knowledge for metrological applications.

Therefore, a survey was designed and implemented for the conduction of a broad user needs analysis, intended to include employees from various companies in German speaking area and from different working fields. The participants were asked to rank on the one hand their existing knowledge in different areas of manufacturing metrology, e.g. hand-held measuring devices, tactile coordinate metrology, optical measuring methods or surface inspection as well as in related topics such as in fundamental

knowledge, e.g. basics of mathematics or geometrical product specification, and competences required for the interpretation of measurement results, e.g. handling of measurement uncertainty and reduction of influences on the measurement results or the further evaluation of a measurement result for quality techniques. On the other hand the participants were asked, if the specified topic is part of their work and to state, if they rate their level of competences as satisfactory for the efficient performance of their tasks or if they feel a need for further training in this area. Also, the number and level of already taken courses on metrological topics were measured together with the support of the enterprise towards further vocational training and the infrastructure at hand.

5.2 First results of user needs analysis

The participants of the analysis so far are mainly working in production control or incoming goods inspection - often both suggesting specialised metrologists. A smaller group is working in product development. The analysis is still going on to enlarge the data basis. Thus, currently all results are to be regarded rather as indicator than as fixed data. Nevertheless, the results found so far do correspond well with former results of user needs analyses' performed for a more narrow scope, e.g. [3] for coordinate metrology.

The results gathered about typical contents of work fit with the theoretical analysis of required metrological competences for the identified user groups, thus confirming the learning objectives derived from the structural analysis. Yet, regarding different areas of metrology, for complex machines the level of knowledge of the participants is mostly limited to the handling of a machine, if it is used in everyday work, respectively very basic knowledge about the machine concept or no idea at all, if the machine is not used. Only for hand-held measuring devices, most participants state to have a profound understanding of function and use.

A similar picture appears for the various topics related to the interpretation of measurement results. Own competences are often rated as insufficient for the proper performance of tasks and there is a high desire on further training, although for most participants related topics were part of previous education. Regarding necessary basics, required competences are generally covered by basic education and no need for further training is seen – with the exception of geometrical product specification, which creates a strong desire for amending training. Given the fact, that all participants stated this subject to be part of their basic education, this desire likely reflects typical problems resulting from differing interpretations of specifications respectively difficulties with function-oriented tolerancing, as problems of this kind have been reported quite often.

Summarized, the analysis shows clearly a demand for as well as a high interest in additional training for the specific areas required for the proper fulfilment of vocational tasks. Yet, there is no special set of competences or knowledge that can be considered as a reliable basis of existing knowledge. Thus, the concept to be defined has to consider the fact, that the same content can be a mere repetition for some learners but a totally new concept or a problematic aspect of required update for others.

Regarding infrastructure, all employees have access on a computer at home as well as in the company, and also most are connected to the internet, but are not used to learning via computer- or web-based offers. Accordingly, conventional seminaries or trainings are preferred, but there is also a broad interest in experiencing new methods of learning. Thus, the teaching-learning methodology can be defined quite freely, oriented towards the best possible imparting of the desired contents, if a proper introduction of the learners to new methods is assured.

Most companies are experienced to act supporting for the participation in further qualification, although only few implement according measures on their own or actively send their employees to courses for improving their theoretical knowledge about metrology. Only the participation in training for handling and programming respectively maintaining a computer-controlled measuring machine, e.g. a CMM, can be regarded as a standard education for all employees working with the machine. On the other hand, in working areas not directly related to active measuring, that is in product development but also in quality assurance, knowledge about metrology is quite low.

It is to be noticed, that especially those whose skills are already above average and who have participated in training on fundamentals are strongly interested to improve their knowledge and to participate in further trainings. This may suggest that the high impact of a proper performance of a measurement on the achieved quality and the level of knowledge required for this when working on complex products with narrow specifications initially is rather not sufficiently perceived by the employees and their supervisors. Then, learning about the many aspects to be considered in metrology causes an enlightening experience and may start the desire for further education on the subject. (This theory is supported strongly by feedback on efforts of learning transfer described by participants in courses on fundamentals offered by the authors, e.g. [4]). Such an underestimation of a working field is on long term dissatisfying and discouraging for the affected employees, but also dangerous for the whole company, if – at the end of a long term development – required resources are not granted and consequently the quality of performance is decreasing [13].

Therefore, besides the need for a proper qualification of those actually involved in handling of measurement results, the general appreciation of the contribution of metrology towards the success of a company and the perception of indispensable necessity for reliable measurement results has to be improved.

6. BASIC CONCEPT OF SPECIFIC TRAINING

Based on the results of user need analysis and the derived learning objectives for the different user groups in the enterprise, training concepts adapted to the specific needs of each user group can be developed. These have to impart the knowledge necessary for the achievement of the specified learning objectives, starting on a very basic level. Here, the curriculum for each group has to be defined specifically according to the learning objectives.

Considering the high diversity of possible participants, the learning concept has to enable for a maximum in flexibility for the adaptation to existing preknowledge or special interests of individual learners. This demands a learning concept with mainly self-controlled learning, suggesting an eLearning-based concept. The necessary infrastructure is available, but as a drawback this learning form is not familiar for many prospective participants. Yet, experience shows that members of the intended target groups are easily capable to use an eLearning-system and even enjoy the advantages, if they have a proper introduction.

Still, it is intended for all user groups to achieve also procedural competences. For this, it is useful to include also face-to-face seminaries, where the abstract concepts can be transferred to actual tasks typical for the user group and also a discussion among learners can take place. Thus, as a basic approach, a Blended Learning concept is recommendable, designed according to the specific needs of each user group.

Yet, as shown in the system analysis, the correct use of metrological information is dependent strongly on a proper cooperation of different areas in an enterprise. To enhance the transferability of imparted abstract knowledge to actual problems in the company, a component of cooperative learning together with members of all other user groups is strongly desirable. Especially useful is the common solving of a given problem in the inter-departmental team, e.g. the inspection- and function-oriented dimensioning of a workpiece and the definition of the according inspection schedule. The cooperative work demands consideration of many different and often contradictory requirements. Thus, to finish the project successfully, not only a proper performance of each individual in his own area of expertise is required, but also the exchange with others, supporting active knowledge management between different areas [14].

Of course, this element of project-work in combined teams will be most useful, if a real problem of the enterprise can be solved as also the increased mutual understanding of different departments will then be most fruitful.

7. CONCLUSIONS AND OUTLOOK

By a structured analysis based on Porter's value chain three typical user groups in industrial companies have been identified with specific need for advanced training on metrological concerns. This analysis provides a base for the development and implementation of demand-oriented training concepts for these user groups.

Following the specified methodology for the development of training offers, in the following steps learning objectives have to be derived from the general systemic analysis of required competences. Based on the developed basic course concept, learning materials can be developed. By conducting a pilot course in an interested company, the concept finally can be evaluated and the impact on the execution of measuring tasks and the connected steps can be observed.

Thus, educational offers can be provided to enable the correct handling of measurement results in industrial application, concerning not only the execution of measurements, but also the interpretation of measurement results and the related communication as well as the basic consideration of inspectional requirements.

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