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New development and distribution concepts for Education in Coordinate Metrology

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Abstract

A key enabler for innovation in manufacturing is the competent use of advanced measuring equipment. As reported [1, 2], operators with their decisions are frequently the most relevant error sources in Coordinate Metrology, especially when dealing with new measuring technologies supporting Digital Manufacturing. In this article, new concepts for structuring of learning material as well as development and distribution of learning material for training in Coordinate Metrology are presented. A 10-steps model is used to structure training material and new tools are presented for a global collaboration in development, updating and distribution of learning material. With the methods used, fast and efficient learning material update and distribution is made available to meet the ongoing development of measuring equipment and international standards and bridge the world of Education and Industry 4.0.

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1. Introduction

Manufacturing in a globalized world is based on multiple suppliers located in different countries and continents. These partners are intensively using automation, data exchange and advanced manufacturing technologies embedded in the digital era.

New opportunities to advance manufacturing are based on the so-called "Industry 4.0" concept that emerges as a key enabler for the integration of the virtual world and the physical world. This opens new challenges and development of advanced design and manufacturing principles, including: interoperability, virtualization, decentralization, real-time capability, service orientation and modularity.

In this context, there is a need of training and education services considering the requirements of the new labour market.

Measuring technologies and in particular Coordinate Metrology are essential tools for the implementation of these activities in modern product engineering and process control; to operate, program and manage the most advanced measuring systems, highly competent and skilled personnel is required that are up-to-date with the actual technology and newest standards.

Innovative learning content development and distribution are needed to allow the adaptation to individual preferences and featuring modern tutor-learner interaction.

2. Coordinate metrology training today

Coordinate Metrology is a subject that is relevant to a number of sectors of industry throughout the EU, as e.g. for the automotive with its sub-contractors and the aeronautical industry.

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Currently, there is still no coherent EU-wide provision of manufacturer-independent vocational education and training on new measuring technologies and standards.

Several inititatives exist side by side for training in coordinate metrology today. Some of the intiatives are AUKOM [3] (**Au**sbildung für **Ko**ordinate**m**esstechnik) initiative with its basis on a national project run in Germany 1998-2001 or the CMTrain (**C**oordinate **M**etrology **Train**ing) association [4] that is a body founded on the basis of the EU project EUKOM (European Training for Coordinate Metrology) with the aim to harmonise CMM training over Europe.

New high quality learning opportunities for lifelong education on innovative measuring technologies (including: industrial computed tomography, fringe-projection and reverse engineering) as well as enriched, updated content from already existing training activities is needed in several languages.

3. Demands in coordinate metrology training

The ongoing fast development in standards in the context of the Geometric Product Specification (GPS) activities lead to the need of a continuous learning material update and the adaptation of learners' competences to be able to speak "one language of specification and verification" in terms of geometric specification and verification.

Namely, the lately published standards as e.g. the ISO 1101:2017 [5] and the ISO 1660:2017 [6] are of big impact on the interpretation of specification and offer availability of new tools for specification. Other important standards are not widely covered in the training of metrologists up to now as e.g. the ISO 17450-1 [7] and other ISO 17450 series. These global standards provide explanations for non-ambiguous GPS language to be used in design, manufacturing and verification, to identify features, characteristics and rules to provide the basis for specifications, as well as consistent rules for verification.

Beside the inclusion of newest standards, the analysis of course feedbacks over the last ten years, covering a number of over 900 participants out of industry and universities, show that there is a big demand in learning material to include:

- Interactivity in learning material using media such as videos, animations, quizzes etc.
- Including comprehension questions in the learning material with immediate feedback
- Fast update of learning material with newest technology
- Having the possibility to choose an efficient learning path (taking pre-knowledge into account)
- Having the possibility to choose an effective learning path (learn only the topics of interest)

Furthermore, the availability of new technologies such as computed tomography (CT), new optical sensors that can be used on CMSs such as chromatic white light sensors, laser-sensors, processing of massive cloud of points, optical coordinate metrology need an update of competences and an overview about possibilities, requirements and restrictions in the application of such systems.

4. Learning material structuring – A ten-step approach

To be able to take the pre-knowledge of the individual learners into account, a fundamental two-level approach to structure the learning modules was chosen. On the basis of this two-level approach further expert modules are developed to meet the topics of the users.

In the two fundamental levels, the learning content is structured in ten sections. These sections are structured in a way that the natural workflow of the metrologists is taken into account. The basis of the concepts is the GPS matrix that structures the standards to be taken into account and as well meets the workflow of the designers as well as the metrologist to a certain extent.

With taking the target group "metrologists" in focus, the outcoming of the design section, with the respective columns A…C in the GPS-matrix, see Fig. 1, is a drawing with geometrical specifications. The approach described here, takes therefore the technical drawing as the starting point for the metrologist.

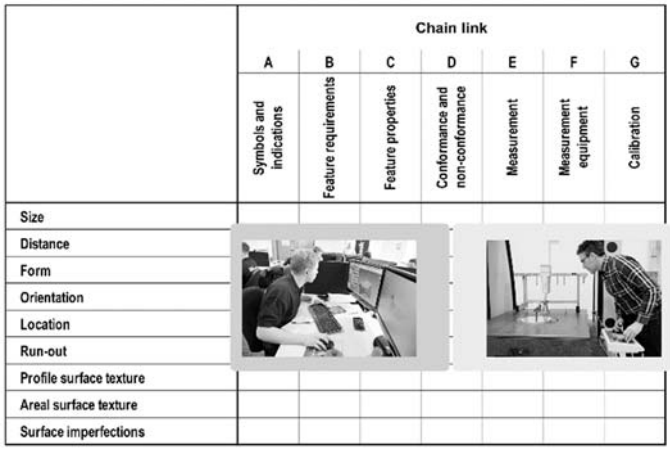

Fig. 1. GPS matrix based on [8] for overview about standards for specification and verification of workpieces

Based on the technical drawing, the metrologist performs a number of actions where the standards in the respective columns E…G in the GPS-matrix, see Fig. 1, have to be taken into account.

These actions are structured in the approach described in this paper in ten sections. Each of these sections contain a number of chapters with learning units that deliver the content to the learner.

Table 1. Overview about a ten-section approach for metrologists

Section	Section title
1	Identification of measurement requirements
2	Measuring strategy definition
3	Equipment selection
4	Workpiece preparation
5	Measuring system preparation
6	Measuring process execution
7	Evaluation strategy definition
8	Measurement uncertainty
9	Documentation
10	Infrastructure and environment

4.1. Section 1: Identification of measurement requirements

The first section covers the interface to the specification. With information out of the technical drawing and other information sources, the requirements for planning and performing the measurement tasks are gained.

Consequently, the learning material covers content for the identification of measurement requirements. Important points and fundamentals for the metrologists are pointed out. These points cover e.g. the GPS system concept, geometric tolerances, drawing indications, dimensions and CAD models.

4.2. Section 2: Measuring strategy definition

Based on the measurement requirements, the points for the measurement strategy are discussed. These steps cover points as e.g. datums and datum systems, coordinate systems, probing strategy as well as the influence of modifiers found in the specification such as e.g. indications for filter settings.

4.3. Section 3: Equipment selection

In section 3, the needs towards the equipment are discussed. This section covers points as e.g. measuring system architecture and measuring system components to be able to choose suitable equipment for performing the measuring procedure.

Important indicators for performance specification of measuring systems and their application as well as restrictions are explained to be able to compare different measuring systems.

4.4. Section 4: Workpiece preparation

Based on the findings in the measurement requirements, important points for the workpiece preparation are pointed out in this section.

In this part, fixturing requirements and constraints are demonstrated, but as well special procedures for surface treatment are covered that are needed e.g. when using certain optical sensors for the use at glossy workpieces.

4.5. Section 5: Measuring system preparation

Section 5 explains the preparation of the measuring systems that covers qualification procedures with its verification in particular. Different probing systems and their needs and procedures together with the artefacts available are discussed in this part.

4.6. Section 6: Measuring process execution

Section 6 covers the important points for measuring process execution such as acquisition of measuring points and measuring conditions based on the findings of the needed measuring requirements.

4.7. Section 7: Evaluation strategy definition

In this section, the association criteria, data processing as well as data analyses and evaluation and data representation are covered.

Beside these topics, this section covers reverse engineering needs and possibilities in particular.

4.8. Section 8: Measurement uncertainty

To be able to apply the decision rules [9], the rules for verifying the conformity or nonconformity with a given tolerance for a characteristic of a workpiece, the metrologists have to be aware of the role of measurement uncertainty and its estimation. In this section, topics as decision rules, relation between tolerance and uncertainty, error sources as well as statistical parameters are covered.

4.9. Section 9: Documentation

In section 9, different forms of measurement result documentation with respect to the target group are covered. The required content of a measurement report is explained as well as the way, how to generate them are discussed.

In this section the possibilities for specific measurement reports such as colour coded deviation illustrations e.g. coming from comparisons of CAD and workpiece deviations or from master workpieces to objects under test are pointed out.

4.10. Section 10: Infrastructure and environment

In an additional step, the need for infrastructure maintenance as well as verification and performance checking and its procedures are explained. Additionally, the need for verification and documentation of other circumstances such as environment conditions are discussed.

5. Learning material design and development

For the learning content development in an international context and environment, a new collaboration form using online sharing of documents for collecting and structuring learning aims was used.

The approach allowed an efficient exchange and collecting of ideas in real time and a collaboration in an efficient and structured way.

Fig. 2. Sharing online documents for collection and structuring of learning aims for coordinate metrology training in the cloud

It turned out that using sharing of documents functionality the group generated a master document for the management and structuring of learning aims that was installed as the basis for the further development process of the whole learning system in different languages.

The experience with shared documents using Excel Online functionality for development process like this was new to the expert group in this field. It turned out that this approach was successful and can be recommended for similar projects. The group will continue to use the approach for the ongoing enlargement of the learning units and for the indication of optimization needs e.g. for harmonizing different languages when need of changes in a certain language have been detected.

By dividing the substantial amount of learning material into manageable parts by defining learning units it was possible to have a fast and efficient way of learning material update over several language versions in an efficient and fast way.

6. Concept of delivery method and didactical approach

The concept of the didactical approach consists of delivering the learning content in a combination of theory and practice.

Before starting the learning process, the learner is being assessed to find the individual needs of trainings. Given this information to the learner, the theoretical background is being elaborated from the learner by using learning material that is made accessible in different forms. The learner can access the learning material by using:

- Tablets
- Smartphones
- Readers
- Computers / Laptops

With the new approach, the learning material is made available over the internet but can be made offline as well e.g. for companies that have restrictions in internet access for their employees.

The already described ten sections, consist of chapters that collect a number of learning units, see Fig. 3.

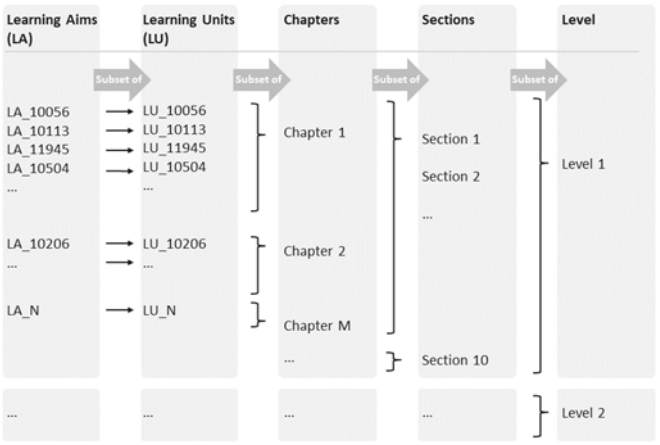

Fig. 3. Learning aims as basis for the development and their relation to learning units, chapters, sections and levels

Each learning unit is structured considering the following points:

- Description of the learning aim
- Introduction to the learning unit
- Explanation of the learning content
- Application examples of the learning content
- Exercises
- Comprehension questions

6.1. Learning aims

Each learning unit starts with an action oriented learning aim description. This learning aim description is the basis for the whole learning unit. Based on this definition all the other information in the learning units are developed.

The learning structure consists of over 400 learning aims that cover the learning needs of metrologists for the first two levels. The learning aims are adjusted in discussions and collaboration in an international expert group of metrologists and expert group of designers. The definition of the learning aims, and the adjustment procedure is being done using real time cooperation with the use of online sharing of learning aim collection. The learning aims are the heart of the development because they:

- help define the course
- help to keep the planning of strategies on track
- help to be in line in the development group
- help to define the course assessment
- tell the learner, the tutor and the developer exactly what is expected

6.2. Introduction

The introduction section of a learning unit gives an overview about the relation to other learning units and gives motivation to the participants for the learning unit.

6.3. Explanation

In the explanation part, the learning content is delivered to the learning. The new tools used to develop and distribute the learning content allow the integration of conventional text, new media to deliver learning content and with that to enrich the learning experience.

In the learning material, new media is used such as:

- Videos
- Animations
- Interactive comprehension questions
- Quizzes
- Fill-in-the-blank text
- Matching exercises

6.4. Examples

In the examples section, each learning unit covers practical examples to demonstrate the application of the learning content. Experience with learning material including such parts show that the learner's motivation can be increased to a high amount.

6.5. Exercises

Easy understandable elaboration examples illustrate the delivered learning content and let the learner elaborate the theory.

6.6. Comprehension questions

Experience with other courses showed that a possibility that allow an immediate verification whether learning content was understood is highly appreciated by students.

Taking this into account, comprehension questions are integrated in the learning content in an interactive way. With this, the learning success can be validated in a self-directed way with immediate feedback. This feedback is for the learner only, if further assistance is needed, the learner can turn to its colleagues or the tutor that coaches the course.

6.7. Workshop

Equipped with the learnings out of the basic part the learner participates a workshop in groups typically 3 to 6 participants. With this setting, it is possible to perform measurement tasks directly on coordinate metrology systems which leads to important experience in metrology by practical work coached by expert tutors.

In these workshop groups discussions can be made that allow to fill participants' knowledge gaps in an individual way. Furthermore, the experience of individual learners can be shared within the workshop groups and further knowledge is created by the participants.

6.8. Examination

In the end, the participants are taking part in an examination. The examination questions are based on the description of the action-oriented learning aims.

7. Conclusion

The international collaboration in an expert group consisting of designers and metrologists for structuring and developing a learning system at the example of coordinate metrology showed that the use of shared online documents that allow real time cooperation in development is a promising way to work together and share ideas.

The structured approach to develop learning material on the basis of action oriented learning aims formulations lead to an effective procedure that supported the harmonization of learning content. Based on the common understanding of learning aims it was possible to install the development of learning material in a parallel procedure that enable higher development speed than in conventional procedures used.

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