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# Competency-Based Learning in the Teaching of Geometrical Product Specifications (GPS)

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## ABSTRACT

The application of the standards system of the Geometrical Product Specifications (GPS) within technical product documentation is associated with challenges. The reasons for this can be seen in the dynamics of standardization, its complexity and the small number of current teaching approaches. In this paper, the learning outcomes and competencies in the field of ISO-GPS are analyzed based on a study on the current state of teaching at universities with mechanical engineering degree programs throughout Germany. A total of 115 universities and 743 potentially relevant courses were identified, with responses from 85 universities being evaluated. What details on learning outcomes are formulated in the module handbooks? Which subject areas of the GPS are they linked to? Which competencies are considered necessary by lecturers or students? In addition to a list of learning outcomes, a competency wheel is presented that includes the learning objective taxonomy, associated verbs and potential methods of teaching. A comparison of the actual and the target status is described. Overall, the study is intended to provide the basis for the assessment and (further) development of teaching approaches for GPS. Selected examples of competencies from the competency wheel are used to illustrate concepts for teaching.

**Keywords:** Competency-based learning, Engineering design, Geometrical product specifications (GPS), Learning objective taxonomy, Teaching approaches

## INTRODUCTION

In the age of globalization and internationalization of companies, the importance of clear technical product documentation is constantly increasing. The language used to describe components in technical drawings with a focus on their function is the Geometrical Product Specifications (GPS) standards system published by the International Organization for Standardization (ISO, 2024) or the ASME Y14.5 standard published by the American Society of Mechanical Engineers (ASME, 2024). In the field of GPS, there are currently 147 ISO standards valid, which are subject to continuous revision (ISO, 2024). Due to the increasing digitalization, the desire for mathematical unambiguity, and the complete coverage of all specification options, the system can be considered dynamic and complex (Gust and Sersch, 2020).

However, this leads to challenges in application that have been highlighted in several studies. For example, in a study by Sersch and Gust (2018), a lack of expertise and skills was identified as the main issue for employees in Germany. Blaszczyk and Humienny (2023) were able to demonstrate a low level of understanding of the GPS system for suppliers in Poland like Toteva and Koleva (2019) for companies in Bulgaria. With regard to training at technical vocational colleges in Germany, it was also confirmed that there are gaps in teachers' knowledge of the GPS system and that the relevance of the topic is often underestimated (Gust et al., 2022). What approaches are emerging to address these challenges? An approach to integrating the GPS system into companies, especially small and medium-sized enterprises, by using agile methods and a maturity model is presented by Schuldt et al. (2020).

When analyzing approaches to GPS teaching, studies in various countries such as China (Kong, 2022) and Germany (Gust and Sersch, 2020) conclude that existing teaching approaches do not fit the needs of learners and are almost never aligned with current GPS content. For the research area of GPS, learner competencies are also rarely the focus of interest. However, as part of the development of the integration concept mentioned above, a training concept is introduced to support the integration process (Schuldt and Gröger, 2023). This includes the idea of GPS competencies assigned to different training levels.

With regard to the training of engineers in general, design training and training in product development were analyzed and recommendations made (acatech, 2012; WiGeP e.V., 2018). As part of the competence approach, problems in the education of future engineers are also identified internationally in order to develop innovative approaches and advance teaching (Almetov, 2020; Caeiro-Rodríguez et al., 2021).

## METHOD

The aim of this study is to analyze learning outcomes and competencies in the field of GPS based on a study on the current state of teaching at universities with mechanical engineering degree programs throughout Germany (Sersch et al., 2023). A total of 115 universities and 743 potentially relevant courses were identified, with the responses from 85 universities being evaluated. Then the module handbooks of these universities were examined manually with regard to the learning outcomes specified for the respective courses.

In order to be able to assign the learning outcomes to their related subject areas of the GPS based on the context of the sentences, the classification into the eight categories of the GPS system was used (Sersch et al., 2023). These are:

1. Concepts, principles and rules
2. Tolerances of form, orientation, location and run-out
3. ISO code system for tolerances on linear sizes
4. Dimensional tolerancing
5. Surface texture
6. Datums and datum systems
7. General tolerances
8. Verification.

When listing the learning outcomes, Bloom's taxonomy of learning objectives (1956) was used in the slightly modified version by Anderson et al. (2001). Furthermore, when considering the types of competence, the definition according to Heyse et al. (2004) is applied, which includes the four basic competences of "personal, social-communicative, professional and methodological as well as activity and action competences". Based on the study by Sersch et al. (2023) and the analysis of the related module handbooks, the following questions are to be answered:

- What details on learning outcomes are formulated in the module handbooks?
- Which subject areas of the GPS are they linked to?
- Which competencies are considered necessary by lecturers or students?

In a next step, a competency wheel for GPS is created based on Brägger and Steiner (2024). It contains the learning objective taxonomy, associated verbs and potential methods of teaching. Lecturers' and students' desires were examined in terms of the competence types. This was followed by a comparison of the results with the competency classification by Schuldt and Gröger (2023) to point out potential discrepancies in regard to the desired learning outcomes and the actual description in the module handbooks. Finally, selected examples of competencies from the competency wheel are used to illustrate concepts for teaching.

## RESULTS AND DISCUSSION

The competency analysis of the module handbooks resulted in the verb assignment in Figure 1, where not only active verbs were assigned to the six categories according to Anderson, but also nouns according to Bloom's definition, but formulated as a verb as well.

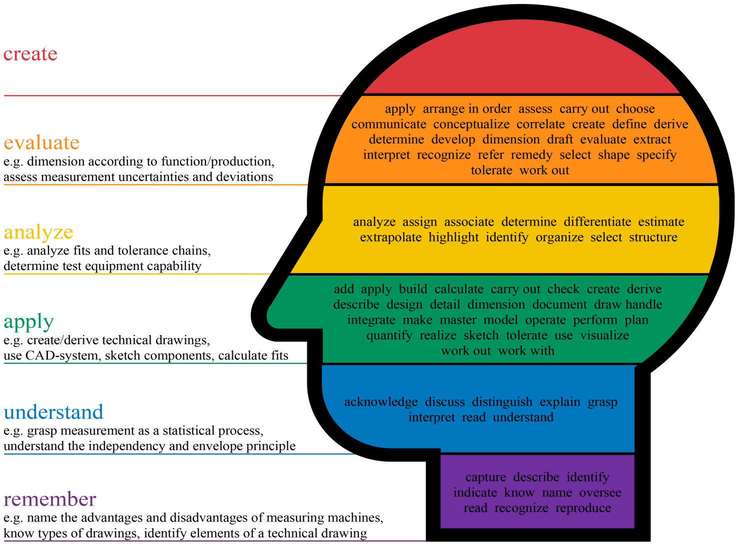


**Figure 1:** Classification of verbs from the module handbooks.

A total of 196 individual courses with at least one of the aforementioned categories of the GPS system as teaching content were reviewed in the sections qualification objectives/intended learning outcomes/competences.

The verbs were assigned subjectively and in relation to the context of the formulation. For example, the verb "*tolerate*" can be found in the taxonomy levels *apply* and *evaluate*. Since "*tolerate components*" is vaguely formulated and lacks context it has been classified as just the application of tolerancing, whereas "*tolerate for functional and manufacturing-compliance*" includes an evaluation with regard to functional and manufacturing requirements. No verbs were assigned to the taxonomy level *create*, because in the field of GPS, it is not the creation of technical drawings that is considered, but the amendment of the standards themselves and their teaching (cf. Schuldt and Gröger, 2023).

In Figure 2 the assigned frequency of words for each taxonomy level to the GPS categories (see section METHOD) is shown. In a) as relative and in b) as absolute frequency. Two further categories have been added, "GPS" and "Technical drawing", because they often are mentioned in general meaning within the module descriptions but could not be automatically assigned to all categories.

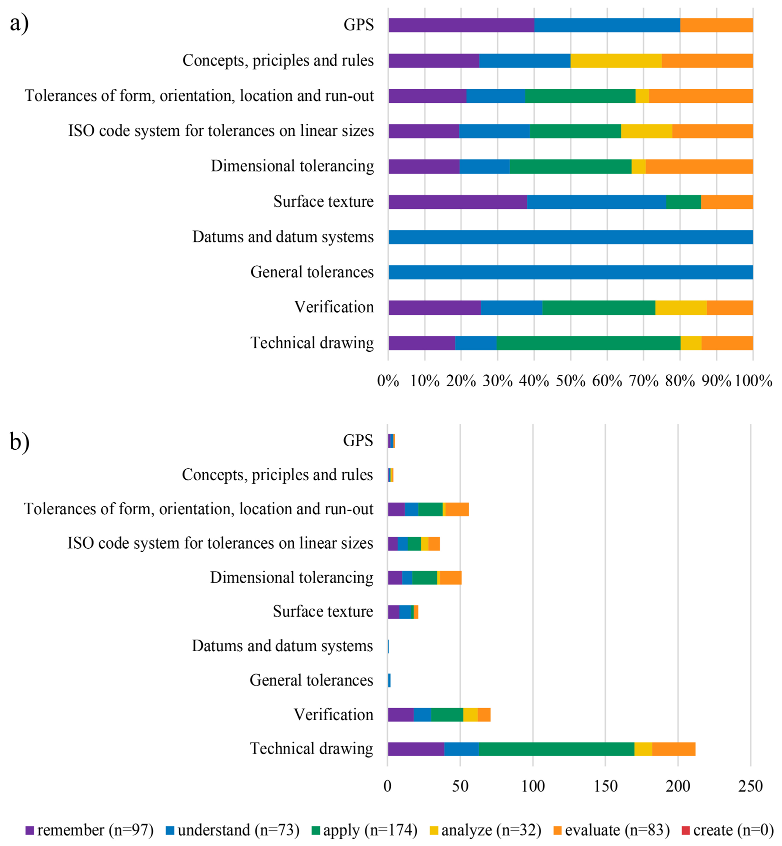


**Figure 2:** Frequency of words for each taxonomy level assigned to the GPS categories a) relative and b) absolute.

Nevertheless, there were learning objectives in the evaluation that could be assigned to several categories, such as in the sentence "*Students are able to analyze required fits and tolerance chains*". In this case, an assignment was made to "Tolerances of form, orientation, location and run-out", "Dimensional tolerancing" as well as "ISO code system for tolerances on linear sizes". Focusing on the colors of each taxonomy level, it is noticeable that there are no verbs for the taxonomy level *apply* in the categories "GPS" and "Concepts, principles and rules". Similarly, no learning outcomes were found that specify that students are able to analyze surface texture after the course. As shown in Figure 2b), the GPS categories "Datums and datum systems" and "General tolerances" appear explicitly once and twice, respectively, in the module descriptions. These formulations contain only verbs that can be assigned to the level *understand*. Overall, formulations of the learning objectives using the term technical drawing were widespread and therefore general. To clarify how the context of the sentences was evaluated, examples of verbs assigned to the GPS categories are presented in Table 1.

**Table 1.** Examples of verbs from the module handbooks assigned to the GPS categories.

| | |
|---|---|
| GPS | • understand the basics of Geometrical Product Specifications<br>• know the ISO-GPS-system<br>• derive the advantages and limitations of the GPS application |
| Concepts, principles and rules | • know the independency and envelope principle and their indication<br>• understand the independency and envelope principle<br>• determine the fundamental tolerancing principle<br>• define components without any doubt and according to the rules of the GPS |
| Tolerances of form, orientation, location and run-out | • identify tolerances<br>• understand tolerances of form, orientation, location and run-out<br>• tolerate components<br>• differentiate standards about tolerances<br>• recognize functions of surfaces from tolerances of form, orientation, location and run-out |
| ISO code system for tolerances on linear sizes | • name types of fits<br>• understand the ISO system for limits and fits<br>• calculate fits<br>• analyze fits<br>• Select fits for functional and manufacturing-compliance |
| Dimensional tolerancing | • know the need for dimensional tolerances<br>• understand the specification of tolerances<br>• apply tolerance calculation<br>• analyze tolerance chains<br>• work out suitable tolerances |
| Surface texture | • know the symbols for surface indications<br>• interpret indications for technical surfaces<br>• apply surface roughness<br>• determine tolerances for surface |
| Datums and datum systems | • understand datums and concepts of alignment |

(Continued)

**Table 1.** Continued

| | |
|---|---|
| General tolerances | • understand general tolerances |
| Verification | • know the measurement of geometrical deviations<br>• grasp measurement as a statistical process<br>• plan machine and process capability tests<br>• evaluate surface, shape and position measurements<br>• correlate measurement uncertainties with requirements |
| Technical drawing | • know types of drawings<br>• understand technical drawings as a basis for communication<br>• visualize components in the form of technical drawings in accordance with standards<br>• analyze technical drawings<br>• carry out drawing critique |

The competency wheel developed for GPS is shown in Figure 3. The learning objective taxonomy can be found in the innermost ring and the associated verbs in the second ring. Potential methods of teaching were derived both from the survey from the lecturers' free responses to the prompt "*Please describe your method/s for the course.*" as well as from publications on GPS teaching (Gust and Sersch, 2020; Li et al., 2022). Subsequently, the methods were assigned to the taxonomy levels subjectively. A notable feature is that the method learning by teaching can be assigned to the level *create*, as GPS content is passed on to other people.

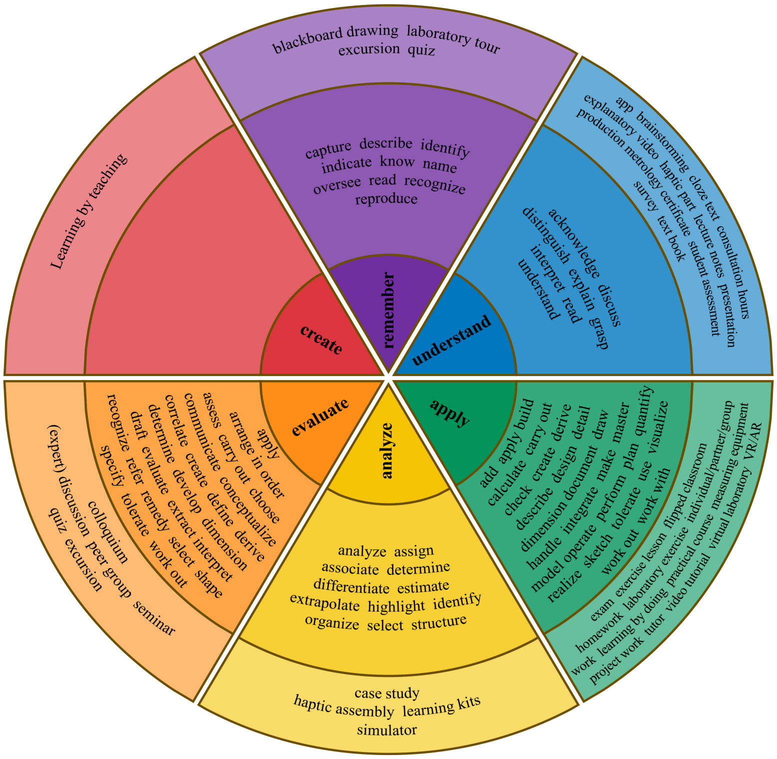


**Figure 3:** GPS-competency wheel according to Brägger and Steiner (2024).

If the assignment of the methods to the competence types according to Heyse et al. (2004) is examined more closely, the difficulty is further increased. Only individual indications of possible categorizations can be identified. Therefore, the assignment in Table 2 has been done using the desires named by lecturers and students in the survey by Sersch et al. (2023). Even though there are mixed forms of competences referring to more than one of the basic competences in Heyse et al. (2004). In the scope of this research and, because of a lack of context given in the answers, the assignment refers only to the main basic competence. Lecturers want the students to have a holistic thinking approach and an interdisciplinary understanding. In their opinion, not only functional requirements for a component, but also manufacturing and assembly considerations should be included in the students' thought process. On the other hand, the students focus more on exams and professional experience as well as sustainable topics. They demand general examples, that cover the main issues rather than highly complex ones.

**Table 2.** Assignment of desires of lecturers (grey) and students (blue) to the competences specified by Heyse et al. (2004).

| | **Personal responsibility** | **Deal with content independently** |
|---|---|---|
| | | (even learning curve of) independence |
| | self-management | self-organization |
| | | independence |
| | | independent learning |
| | | preparation |
| **Personal competence** | commitment | commitment |
| | creative activity | creativity of the design process |
| | holistic thinking | more comprehensive system considerations |
| | | own designs |
| | | understanding the interrelationships in complex assemblies |
| | | recognize the practical benefits of the lecture content |
| **Social-communicative competence** | ability to experiment | learning by trial and error |
| | problem-solving ability | problem-based learning |
| | discipline | participation in voluntary events |
| **Professional and methodological competence** | interdisciplinary understanding | cross-modular |
| | | functionality of products as well as manufacturing and assembly processes |
| | | better linkage |
| | expertise | relevant, no pigeonholing |
| | | professional experience |
| | systematic and methodical approach | design high-performance technical systems |
| | awareness of consequences | understanding the interrelationships in complex assemblies |
| | | valuable insights for later working life |
| | teaching ability | own "teaching" |
| | analytical abilities | understanding the interrelationships in complex assemblies |
| | | recognize errors haptically |
| | knowledge orientation | professional experience |
| | | sustainable topics |

(Continued)

**Table 2.** Continued

| | | |
|---|---|---|
| **Activity and action competence** | readiness for implementation | practical disposition |
| | | motivate |
| | | put into practice what you have learned |
| | initiative | interested students |
| | design capability | design high-performance technical systems |
| | optimism | enjoyment of the design process |
| | | density of content is perceived as pressure, fear of failure |
| | results-oriented action | standardized tasks |
| | | clearer focus on the exam |
| | | receive action plans |

Limitations of the findings are, for example, subjectivity and a potential bias due to the translation into English. Furthermore, the survey did not explicitly ask about competencies, which brings additional interpretation to the statements. The analysis also only covered the Bachelor's degree courses in mechanical engineering in Germany with different focus areas, which cannot be precisely assigned here. Only the module handbooks of courses with an answer in the survey were analyzed. The development of the competency wheel and the competence tables was based on data from the survey and selected publications. Complete coverage of all possible methods in the adapted competency wheel is therefore not guaranteed.

## CONCLUSION

This study looks at learning outcomes and competencies in the field of GPS. A comparison of the results of previous studies, such as the competency classification by Schuldt and Gröger (2023), highlights the different perspective of this study. Module handbooks are examined with regard to the description of courses in the bachelor's degree program in mechanical engineering and the results of a previous survey at German universities (Sersch et al., 2023) are used as a further basis, whereas Schuldt and Gröger (2023) focus on the professional GPS application. Bloom's interpretation of the levels is similar, but they consider the taxonomy levels *evaluate* and *create* (synthesis) together. The *create* level in the sense of creating/changing standards and transferring content is understood in the same way. An overlay of the two approaches shows that the *create* level is required in the profession but is not achieved or focused in academic teaching. According to the survey results, the reasons for this are that GPS is usually taught in the first three semesters of the studies and that lecturers have too little time to teach it.

For further studies in the field of GPS teaching it should be considered that students want to learn in a result- and practice-oriented way. At the same time, they demand a level of complexity that does not overwhelm. This can be a major challenge for the development of teaching examples. When the identified learning outcomes, teaching and learning activities, and assessment are considered together according to Biggs and Tang's (2011) constructive alignment approach, the assessment should not necessarily be designed for the first three levels of the taxonomy. Transfer achievements and consideration of the level *create* must subsequently be planned for the descriptions in the module handbooks, for example by means of learning by teaching and more time for teaching. Holistic and interdisciplinary thinking can be expanded as a competence by coordinating with other modules or optional courses. A fundamental finding is that the formulations in the module handbooks are not consistently implemented in a competence-oriented manner and are not linked to all relevant subject areas of the GPS system.

Learning by teaching, discussions, excursions and haptic assemblies appear to be potentially promising methods. These also might help to promote the types of competences described by Heyse et al. among the students. Other known methods need to be evaluated for use with GPS teaching in future studies and surveys. For example, a survey on competences and competencies in the teaching of GPS as well as an analysis of all module handbooks of relevant engineering courses in Germany should be conducted as it was a limitation before.

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