On the acquisition of GNSS competencies hand in hand with personal competencies in the introductory phase of BSc engineering degree programs

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Key words: Education of young surveyors, higher education, introductory phase, research-oriented teaching, competency-oriented teaching

SUMMARY

Using the example of a 3 ECTS GNSS-related lecture of the introductory phase (second semester) of the degree BSc program ‘Geodesy and Geoinformatics’ of Karlsruhe Institute of Technology (KIT, Germany) held in German language, it is shown how discipline-related and personal competencies are acquired hand in hand based on a well-considered didactic mix of methods. This happens, for example, in the context of scientific work (e.g., understanding papers), training of presentation skills (e.g., peer teaching), support of individual learning competency (e.g., application of different learning techniques), and training of reflectivity competency (e.g., analysis of individual learning process). In addition, the lecture takes into account fundamental psychological needs of students (Deci & Ryan 2000; e.g., experience of autonomy, experience of competence) and thus supports motivation.

The didactical framework of the lecture is based on Anchored Instruction (Cognition and Technology Group at Vanderbilt 1993). For this purpose, a scientific paper – dealing with the establishment and application of a regional NRTK service – is used. The subject-related understanding level is chosen with mindful consideration, enabling the students – while reading the paper in the beginning of the lecture for a first time – to individually (i) reflect their previous GNSS knowledge and (ii) realize GNSS aspects, which are not fully graspable. According to principles of research-oriented teaching (KIT 2018), questions related to the scientific paper are jointly formulated, which will be dealt with and answered throughout the lecture. Re-reading the paper at the end of the lecture enables the students to experience their personal competency gain, which supports their motivation (Deci & Ryan 2000).

In order to enable students to cognitively connect consecutive teaching/learning units (unit length: approx. 90 minutes), the ending and beginning of each unit are ritualized (e.g., ending: students individually reflect on the most important aspects, open questions and topics of the following units). This collection generates valuable feedback for the lecturer, increases transparency regarding the students’ learning processes, and allows to mindfully plan the next steps of the lecture. Thus, the challenges of increased online teaching during the COVID-19 pandemic could be handled easily.

At FIG 2022, the teaching/learning setting of the lecture is described and discussed in detail, with an additional focus on the effects of the COVID-19 pandemic.

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1. ACQUISITION OF COMPETENCIES AND SELF-DEVELOPMENT AS AIM OF HIGHER EDUCATION DEGREE PROGRAMS

Higher education aims at qualifying young people by extensive scientific education and imparting interdisciplinary competencies (KIT 2018). Based on their individual learning process, at the end of their studies they are particularly able to identify current and future challenges, work on complex tasks, and develop sustainable solutions with the help of scientific methods. To reach these aims, the strategy of research-oriented teaching is proven to be an appropriate tool, especially when discipline-related paradigms are taken into account.

In research-oriented teaching, teaching and learning activities directly refer to scientific work. This interlinks the theoretical and practical parts of degree programs. In addition, research-oriented teaching interlinks the process cycle of scientific knowledge acquisition (research; Figure 1, outer cycle) and the individual competency acquisition process cycle (learning; Figure 1, inner cycle). Thus, typical research activities become integral constituents of the students' learning processes. See Healey & Jenkins (2005) and Jenkins et al. (2007) for details on linking research and teaching. In addition, Healey (2013) is referred for a massive bibliography on this extensively researched topic.

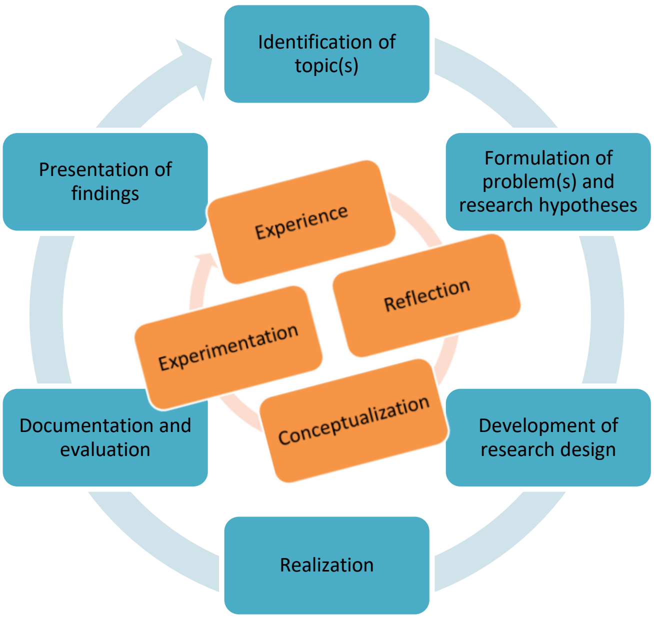

Figure 1: Process cycles of scientific knowledge acquisition (research, outer cycle, according to KIT 2018) and students' competency acquisition (learning, inner cycle, according to Kolb 1984).

Research-oriented teaching has become a widely accepted and variously applied fundamental teaching concept. This results in a plurality of conceptions. In order to distinguish between realizations of research-oriented teaching, the Healey and Jenkins model (Healey & Jenkins 2009) can be applied. This model uses the two characteristics (i) active participation of students and (ii) focus of research process (Figure 1).

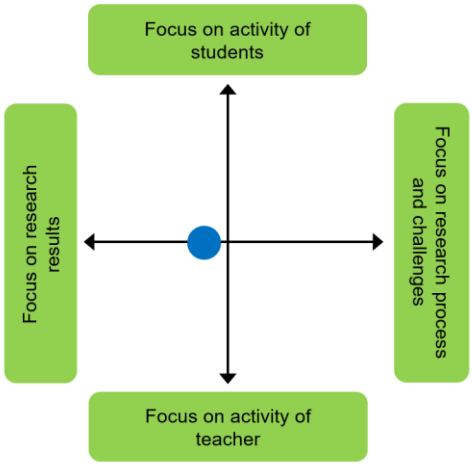

Figure 2: Healey and Jenkins model (Healey & Jenkins 2009) to classify research-oriented teaching; blue dot represents the research orientation in teaching of the lecture 'GNSS-based Positioning'.

Based on well-planned teaching settings, students individually acquire competencies of various dimensions throughout their higher education. As basis for this paper, which deals with the acquisition of competencies within a German language Geodesy-related degree program, the discipline-specific qualifications framework 'Geodesy and Geoinformation' FQR_GG (2018) is used. For a general review on the 'construct competency' see Salman et al. (2020).
The FQR_GG was developed formally based on the European Qualifications Framework (EQF 2018), the German Qualifications Framework (DQR), and the Qualifications Framework for German Higher Education Degrees (German Rectors' Conference 2005). The FQR_GG distinguishes between

- professional competencies,
- methodological competencies,
- social competencies, and
- self-competencies.

For compiled details on FQR_GG see Mayer et al. (2022).
As example for the individual process of young surveyors to acquire competencies, the BSc degree program 'Geodesy and Geoinformatics (GaG)' of Karlsruhe Institute of Technology (KIT, Germany) held in German language is analyzed. In detail, representative components of the research-oriented teaching concept of the lecture 'GNSS-based Positioning' of the introductory phase (second semester; 3 ECTS, EC 2022) is presented, where GNSS competencies are acquired hand in hand with personal competencies. This approach particularly supports students …

- in deep learning (Marton & Saljo 1976a/b) and

- to reflect on research-related competencies.

In section 2 of this paper, the challenges which often are associated with students' first year experiences related to higher education of German engineering degree programs are described. This motivates for a lecture design especially supporting students in their introductory phase. Section 3 focusses on the acquisition of competencies within a specific Geodesy-related lecture of the introductory phase of the degree program 'Geodesy and Geoinformatics' held in German language at Karlsruhe Institute of Technology (Karlsruhe, Germany). The teaching and learning setting of the lecture is presented and representatively selected components of the lecture are classified with respect to (i) motivation and psychological needs of students and (ii) research-oriented teaching. In addition, the role of the lecture within the degree program is described analyzing cross-cutting competencies (e.g., presenting). The paper closes in sect. 4 with conclusions and an outlook on future modifications of the lecture.

2. CHALLENGES OF INTRODUCTORY PHASE OF HIGHER EDUCATION DEGREE PROGRAMS

In Germany, after graduating at a school of lower secondary education level, young surveyors can choose an individual career pathway in higher education (tertiary education level) at e.g., universities (KMK 2019). The successful individual management of this transition process is a big challenge.

Analyzing the design of KIT's BSc GaG degree program, the introductory phase is dominated by fundamentals in Mathematics, Physics, and Informatics, while topics of the discipline Geodesy are less represented; see Table 1 for a comparison to higher semesters. In addition, fundamental topics are often criticized as (i) ambitious and (ii) not well-linked to discipline-specific topics. This can lead to motivational challenges for example. In order to support students in successfully facing these challenges autonomously, KIT's GaG degree program is continuously further developed. Recent progress is for example aiming at

- increased students' self-competency (e.g., units focusing on learning techniques),
- increased lecturer awareness of diverse student body (e.g., training for lecturers),
- actions to increase students' intrinsic motivation (e.g., sharpening of discipline resp. job profile),
- explicit exchange about current challenges and collaborative development of the degree program (e.g., joint student-lecturer project focusing on students' needs due to the COVID-19 pandemic),
- establishment of low-threshold monitoring systems for students' success (e.g., polls at the beginning of the second semester regarding (i) satisfaction with choice of degree program, (ii) reasons for non-participation in exams).

These measures support improved onboarding. Embedded in this framework, Geodesy-specific lectures of the introductory phase are of significant importance for the academic success.

This framework motivates for a lecture design especially supporting students in their introductory phase. The upcoming section focusses in this context on the lecture 'GNSS-based Positioning'.

Table 1: Semester-specific ECTS numbers of KIT's GaG degree program (180 ECTS)

	Semester					
	1	2	3	4	5	6
Fundamentals	20	16	7	0	0	0
Geodetic topics	9	15	23	32	26	26
Key competencies	2	1	0	0	2	1

3. ACQUISITON OF COMPETENCIES WITHIN 'GNSS-BASED POSITIONING'

Using the example of the 3 ECTS lecture 'GNSS-based Positioning' of the introductory phase (second semester, approx. 20 participants) of the BSc degree program GaG, it is shown how GNSS-related and personal competencies are acquired hand in hand based on a well-considered didactic mix of methods. Within this lecture, the open-source learning management system ILIAS (https://www.ilias.de/en/) is particularly used …

- to communicate using forums and mail,
- to provide lecture notes, videos, and additional material for the students, and
- to enable students to upload measurements data, presentations, and individual reflections.

Section 3.1 focusses on the teaching/learning approach of the lecture. In sect. 3.2, the lecture is classified with respect to motivation resp. psychological needs of students and research-oriented teaching. The role of the lecture in the GaG degree program is discussed in sect. 3.3.

3.1 Teaching/learning approach and set-up of the lecture 'GNSS-based Positioning'

The lecture and therefore the teaching/learning setting is framed in two ways: lecture-related (sect. 3.1.1) and unit-related (sect. 3.1.2). Both frameworks support students to regularly train their reflective skills. The importance of reflective skills as a means of increasing students' learning has been widely researched (Rogers 2001). Further selected components of lecture are described in sect. 3.1.3.

3.1.1 Anchored Instruction as lecture-related framework

The didactical framework of the lecture is based on Anchored Instruction (Cognition and Technology Group at Vanderbilt 1993). For this purpose, a German language scientific paper is used. The paper deals with the establishment and application of a regional NRTK service in the context of the Fehmarnbelt tunnel linking Denmark and Germany (Jensen & Almholt 2015; for recent details see https://femern.com/). The subject-related understanding level of the paper is chosen with mindful consideration, enabling the students – while reading the paper in the beginning of the lecture for a first time – to individually (i) reflect their previous GNSS knowledge and (ii) realize GNSS aspects, which are not fully graspable. According to principles of research-oriented teaching (KIT 2018), questions related to new/unknown GNSS aspects of the paper are collected. Therefore, each student is asked to submit 8-12 questions, whose answers would increase the individual comprehension level of the paper. These questions provide valuable information – for the lecturer and for fellow-students – regarding the individual student's status related to the a-priori GNSS competency level. In addition, after clustering the questions, they provide the teaching agenda for the lecture. Re-reading the paper at the end of the lecture enables the students to experience their personal competency gain, which supports their intrinsic motivation (Deci & Ryan 2000).

3.1.2 Unit-related framework

In addition to the lecture-related framework (see sect. 3.1.1), the ending and beginning each 90-minute unit (number of units: 14) is ritualistically framed supporting students ...

- to cognitively connect consecutive teaching/learning units,
- to improve their reflectivity competency, and
- to apply learning techniques.

After each unit the students individually reflect the outcome of the recent unit based on questions. Examples of questions are shown in Table 2 (left column). In the right column of Table 2 the main purposes of the students' reflections are presented.

Table 2: Translated questions (left) and main purposes (right) related to reflections carried out by students after each teaching/learning unit of the lecture 'GNSS-based Positioning'

Questions supporting students' reflections asked at the end of each teaching/learning unit	Main purposes of question [dimension within the teaching/learning process]
Which three aspects of the current teaching/learning unit have been most significant for me personally?	• Generating of valuable feedback on students' learning processes for the lecturer [adaption of joint teaching/learning process regarding learning outcomes of the lecture] • Weighting of topics [improve students' learning techniques] • Collection of most important topics regarding the exam [transparency regarding the exam]
What would I like to learn more about?	• Generating of valuable feedback (e.g., open questions) on students' learning processes for the lecturer [adaption of joint teaching/learning process regarding learning outcomes of the lecture] • Students have influence on the learning process [increase students' motivation]
How satisfied am I with the lecture so far? (Think of a scale from 1 to 10, where 1 corresponds to total dissatisfaction and 10 corresponds to the best possible satisfaction, and rate your personal current satisfaction.)	Comparison of perceptions [improvement of teaching/learning process by means of regular evaluation, in addition to KIT's one-time evaluation of each lecture per semester]
What can Michael Mayer do to increase my personal lecture-related satisfaction level by +1? (Name only the aspect that is most important to you.)	Revealing potential for improvement regarding … • teaching/learning process of the lecture [adaption of joint teaching/learning process regarding learning outcomes of the lecture] • design of students' self-learning phase [improve students' learning techniques]
What can I do myself to increase my personal lecture-related satisfaction level by +1? (Name only the aspect that is most important to you.)	Emphasis on students' ownership of the learning process [improve students' learning techniques resp. mind-set].

Based on the mandatory students' reflections, the agenda of the follow-up unit and the beginning are planned. A unit covers either theoretical or practical teaching/learning settings held either in the classroom, hybrid, online or in the field.
In the beginning of the follow-up unit, the responses of the students are presented using word clouds. This enables students to orientate themselves with respect to their fellow-students. In addition, the most important open questions are discussed.

3.1.3 Selected further components of lecture

Beside the above presented main components of the lecture, there are further components. Selected further components of the lecture and their purposes are:

- GNSS-related excursions and presentations of alumni support the students in sharpening of discipline resp. job profile.
- Insights into recent GNSS-related research projects are given at the end of the lecture in order to brighten students' perspective. While the lecture mainly focusses on positioning principles and handling of limiting effects in order to determine reliable coordinates, the focus of this element of the lecture is on remote sensing of the Earth's atmosphere based on GNSS measurements. This (i) allows the students to realize the importance of being able to change perspectives, (ii) emphasizes the importance of basic GNSS understanding for environmental sensing, and (iii) provides further insights in research-related thinking concepts.

3.2 Classification of lecture

In order to achieve learning outcomes, a variety of teaching/learning approaches can be used. For comparison purposes, the applied teaching/learning approach of 'GNSS-based Positioning' (see sect. 3.1) is analyzed with respect to ...

- the concept of understanding human's motivation and psychological needs (Deci & Ryan 2000) and
- the process cycle of scientific knowledge acquisition (see Figure 1).

As stated in sect. 2, the academic success of GaG students can be supported when taking into account teaching approaches, which have a positive impact on students' intrinsic motivation. Due to the diverse composition of students of one semester, various offers have to be made. According to Deci & Ryan (2000), motivation can be supported regarding the cross-culturally valid dimensions autonomy, competence, and relatedness. Autonomy refers to a feeling of voluntariness that can accompany any behavior (e.g., following instructions if one is convinced of the instructions' necessity); thus, in this context, autonomy is not to be understood as objective independence from persons or circumstances. Competence is understood as the feeling of being able to effectively influence aspects that are considered important and to achieve desired results accordingly. Relatedness is related to personal relationships as well as belonging to groups and focusses on the meaning that others have for one and vice versa. Table 3 summarizes, in which way these psychological needs are taken into account within 'GNSS-based Positioning'.

Table 3: Components of the lecture 'GNSS-based Positioning' supporting students' intrinsic motivation by taking into account psychological needs.

Dimensions of psychological needs	Selected components of the lecture 'GNSS-based Positioning'
Autonomy	• Students select individual subject-related topics, in which they act as experts • Students choose subject-related aspects, which should be treated next (see sect. 3.1.2) • Students individually select best-fitting time slot, in which practical training is carried out
Competence	• Students act as experts and present findings to class • Students carry out GNSS measurements, which will be evaluated in the lecture • Students give peer-feedback • Students recommend measurement set-up of practical training of next semester
Relatedness	• Students act as experts and present findings to class • Students carry out practical experiments in groups • Students discuss selected topics in groups • Students give/receive peer-feedback

Besides analyzing the teaching/learning concept of lectures with respect to the model of Deci and Ryan, research-oriented teaching can be classified by relating teaching/learning components to the process cycles of scientific knowledge acquisition (see Figure 1). In Table 4 examples and the extent of consideration of components of the process cycle of scientific knowledge acquisition are presented.

Table 4: Extensive (turquoise), significant (green), minor (yellow), no (red) consideration of components of the process cycle of scientific knowledge acquisition within the lecture 'GNSS-based Positioning'

Components of process cycle of scientific knowledge acquisition	Consideration in the lecture 'GNSS-based Positioning'
Identification of topic(s)	Students understand scientific literature.
Formulation of problem(s) and research hypotheses	During the analysis of GNSS measurements students train to formulate hypotheses based on principals of discovery learning (Svinicki 1998).
Development of research design	Students recommend next semester measurement set-up regarding code-based measurements; students rate quality of measurement approaches.
Realization	Students carry out practical training related to code- and RTK-based measurements.
Documentation and evaluation	Students evaluate GNSS measurements.
Presentation of findings	Students present findings (e.g., data evaluation, scientific papers) to fellow-students; students gain insights into structure of scientific papers.

3.3 Embedding of 'GNSS-based Positioning' in BSc degree program

During the previous sections, the focus was on the lecture 'GNSS-based Positioning'. This section describes the role of the lecture in the BSc GaG curriculum based on the three important cross-cutting competencies (i) presenting, (ii) programming, and (iii) learning.
Within GaG and research in general, the presentation of findings is of high importance. Therefore, repetitive training events are integrated in subject-related lectures. While during the first semester fundamental competencies in 'Scientific Presentation Techniques' were acquired, within 'GNSS-based Positioning' peer-to-peer teaching (Stigmar 2016) is applied. As students

act – for a self-chosen GNSS-related topic within a team of two students – for ca. 30 minutes as teachers for their fellow-students, added value is created (e.g., active and research-oriented collaboration is supported, students' responsibility generates intrinsic motivation, deep learning is supported, social and self-competencies are implicitly trained). All student teams are individually guided by the lecturer through their individual process in order to guarantee good quality and best-possible support (e.g., 2-3 meetings). Based on feedback received from fellow-students and the lecturer as well as the individually gained experiences within 'GNSS-based Positioning', the students set individual goals regarding presentation competency for upcoming semesters. These goals are communicated among the GaG lectures in order to be able to individually support the students' processes throughout their study.
In addition to fundamental competencies related to programming and programming languages (e.g., C++, Java), which are acquired in German language lectures like 'Programming for Geodesists', within 'GNSS-based Positioning' the students gain first experiences in using MATLAB (e.g., reading data, creating plots, outlier detection). MATLAB is a programming and numeric computing standard platform used by engineers and scientists to analyze data and develop algorithms (https://www.mathworks.com) and therefore of high importance for the academic success within GaG and research in general. Within GaG, lecturers jointly developed a catalog of MATLAB-related competencies, which – starting from the second semester – are (i) based on each other and (ii) trained in different lectures resp. semesters.
The further development of the self-regulated learning strategies of students is of fundamental importance for academic success and lifelong learning (Anthonysamy et al. 2020). Therefore, the lecture 'GNSS-based Positioning' focusses on this cross-cutting competency. In addition to the mandatory students' reflections on improvement regarding their learning methods and strategies (see Table 2), each student is asked after the fourth unit to visualize the personal higher education learning philosophy. This explicit individual reflection improves the meta-cognitive learning competency of the students and provides valuable insights into students' learning for the lecturer. In addition, this component of 'GNSS-based Positioning' enables students to orientate themselves with respect to their fellow-students and implicitly supports students to further develop their learning mind-set. The exam related to 'GNSS-based Positioning' is the first higher education oral exam for most students. Therefore, a live exam demo is carried out with the students. This component and the follow-up discussion (i) supports the students to reflect on their learning strategy regarding oral exams, (ii) establishes transparency, and (iii) can help to reduce exam anxiety.

3.4 Adaptions as a result of the COVID-19 pandemic

The lecture 'GNSS-based Positioning' is held in summer terms, therefore in 2020 due to official guidelines (e.g., State Government of Baden-Württemberg, KIT) related to the COVID-19 pandemic, the lecture was given online without any personal contact to students, practical training or excursions. In 2021, minor practical training was carried out. In both semesters, all units were held (i) as live online meetings via zoom (https://zoom.us/), which were recorded and provided via ILIAS, or (ii) based on teaching videos provided via ILIAS.
In order to support students in their self-regulated learning, compared to teaching in the pre-COVID-19-era, more mandatory achievements were established. This supports keeping in

contact and supervision of students' learning process. Most of these achievements will also be used in the post-COVID-19-era, because of the valuable information which could be gained for the lecturer. In order to reduce lecturer's workload, increased peer-to-peer responsibility is planned.

In the last two summer terms, the oral examination was carried out online, while in previous semesters the exam was carried out requiring personal attendance. In the future, as far as KIT guidelines allow for this, the decision regarding, how the exam will be carried out, is planned to be left to the students.

Based on the gained experience and the digital competencies of students and lecturer, the variety of teaching methods is increased. Therefore, context-related (e.g., health situation, GNSS topic, preferences of the students) decisions will be made regarding the optimal teaching/learning setting for the achievement of learning outcomes of the lecture. In general, more complex GNSS topics will be treated in a flipped classroom approach (Bates et al. 2016).

4. CONCLUSION AND OUTLOOK

Using the example of a 3 ECTS GNSS-related lecture of the introductory phase (second semester) of the BSc degree program 'Geodesy and Geoinformatics' of Karlsruhe Institute of Technology (KIT, Germany) held in German language, it is shown how discipline-related and personal competencies are acquired hand in hand based on a well-considered didactic mix of methods. This happens, for example, in the context of scientific work (e.g., understanding papers), training of presentation skills (e.g., peer teaching), support of individual learning competency (e.g., application of different learning techniques), and training of reflectivity competency (e.g., analysis of individual learning process). In addition, the lecture takes into account fundamental psychological needs of students (e.g., experience of autonomy, experience of competence) and thus supports students' motivation during the challenging introductory phase of the degree program.

The didactical framework of the lecture is based on Anchored Instruction (Cognition and Technology Group at Vanderbilt 1993). For this purpose, a scientific paper is used. The subject-related understanding level is chosen with mindful consideration, enabling the students – while reading the paper in the beginning of the lecture for a first time – to individually (i) reflect on their previous GNSS knowledge and (ii) realize GNSS aspects, which are not fully graspable. According to principles of research-oriented teaching, GNSS-related competencies are acquired dealing with details of the scientific paper.

In order to enable students to cognitively connect consecutive teaching/learning units, the ending and the beginning of each unit are ritualized (e.g., ending: students individually reflect on most important aspects, open questions and topics of the following units). This collection generates valuable feedback for the lecturer, increases transparency regarding the students' learning processes, and allows to mindfully plan the next steps of the lecture. Thus, the challenges of increased online teaching during the COVID-19 pandemic could be handled easily.

In the summer term 2022, KIT's expectations are that classroom teaching will become the standard way of teaching again. But during the last two years valuable and persistent experiences regarding synchronous and asynchronous teaching/learning settings were gained. In addition, hybrid settings will gain in importance. Therefore, it is expected that the upcoming semesters will become transition semesters as well. In contrast to the last four semesters, in which – caused by the COVID-19 pandemic – the digital transformation of higher education competency acquisition processes was accelerated disruptively (e.g., Hodges et al. 2020), the upcoming semesters are characterized by a large opportunity space for changes in teaching and learning. Within 'GNSS-based Positioning' it is planned for example to …

- increase the level internationalization by establishing joint teaching components with Universidade Federal de Santa Maria (Brazil),
- support the students to set up guidelines for oral examinations,
- include a reflection on Perry's model on 'Patterns of Development in Thought and Values of Students' in order to increase students' meta-cognitive learning competency (Perry 1968), and
- integrate the effective programming language python (https://www.python.org/).

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BIOGRAPHICAL NOTES

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