An innovative teaching approach in Engineering Education to impart reflective digitalization competences

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Abstract—**This paper presents a novel theory-based teaching concept for bachelor students on the subject of "digitalization". The constant increase of changes driven by the surrounding context of digitalization affects all areas of industry and social life. Consequently, there is an urgent need to anchor the topic of digitalization in a holistic approach in engineering education. This paper contributes to the research discourse on suitable implementation methods in the teaching-learning module "Summer School Technology 4.0: Digitalization". The contribution aims to generate new insights for engineering education practice and research (1) by classifying the significance of "digitalization" in the research landscape of engineering didactics, (2) by demonstrating the diversity-oriented and student-centered theoretical study approach of the teaching-learning concept and the embedding in the research of teaching-learning, (3) through the presentation of the methodological-didactic design of the course and its implementation in engineering education, and (4) by the introduction of the evaluation concept in mixed method design.**

Keywords—digitalization; digital transformation; student diversity; mentoring

I. INTRODUCTION

Digitalization is leading to major changes in the industrial, social and private sectors, e.g. [1] and is present as a further focus in engineering research. Fig. 1 shows results of a category-led analysis of the conference papers of the IEEE EDUCON 2014-2016 [2], which points to the importance of digitalization in research. For example, digital editing grew from 2015 (22 paper) to 2016 (46 paper) and consequently another differentiation revives the large thematic spread of the subcategories in the field of "digitalization" [ibid.].

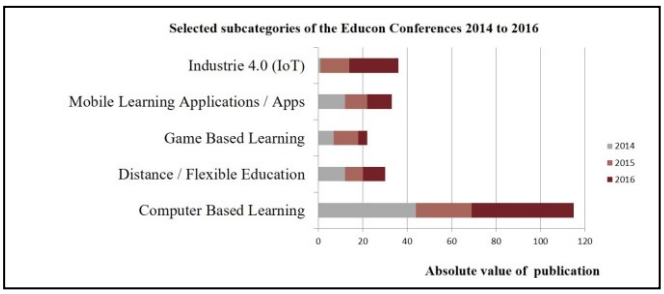

Fig. 1. Selected subcategories focusing on digitalization, contributions of the IEEE Educon Conferences 2014 to 2016, following [2]

The effects of digitalization are also strongly felt in the field of engineering teaching, e.g. [3], as the requirements for the teaching content and competence profiles of students and graduates change, e.g. [4]. On the one hand, for a digital expert technical skills are increasingly demanded and generally a higher qualification of the people, on the other hand the creative and socially interactive activities are becoming increasingly important in the wake of the digital transformation [5]. This brings new challenges for the design of adequate learning and teaching processes: How must innovative teaching and learning concepts be designed that address the topic of digitalization in a professional way and enable a comprehensive and digital skills-based competency development of the students? How can students' reflection on the complex effects of digitalization be integrated into the teaching-learning concept?

This work in progress paper contributes to this existing international discussion on the need to change engineering teaching with special emphasis on digital transformation. Section II introduces the theoretical framework of a teaching concept that focuses on this question. Section III outlines the methodological didactic design and its implementation in teaching. Finally, Section IV presents the evaluation design for student competence development.

II. THEORETICAL FRAMEWORK OF THE TEACHING CONCEPT

A. Motivation and objectives of the teaching concept "Summer school 4.0: digitalization"

To inspire students (and possible young talents) for innovative technical topics such as digitalization, to stimulate them to engage in independent, in-depth scholarly debates with the topic and, at the same time, to take account of responsible action and critical reflectivity are challenges in engineering teaching. This problem is addressed by the teaching concept "Summer School 4.0: Digitalization", as it equally addresses the teaching of technical and interdisciplinary competencies (more detail in Sec. IIb). Undergraduate students plan summer education for pupils by exploring and developing two-day projects for this summer school.

The name of the course was chosen based on the German term "Industrie 4.0" (similar to the term Industrial Internet of Things – IIoT) and intends to emphasize the innovative

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approach of the methodological-didactic concept. The module will be opened for all undergraduate students (semesters two to five). On the one hand, the diversity of the subject-related anchoring of the students (besides engineering also business administration, environmental sciences, information systems, education and psychology) is to contribute to the interdisciplinary discussion of the topic and to stimulate reflection processes on the opportunities and risks of the digital transformation. The second innovation is the assumption of a mentoring role by the students, through which especially the social and personal competences are integrative strengthened. During the semester, theoretical foundations are developed in the field of digitalization as well as digital transformation and consequently put into practice on the basis of small research and development projects. Simultaneously, the students will design a two-day summer school on "digitalization" with the aim of implementing these projects in tandem with pupils from surrounding high schools. Through the implementation of the summer school the students deepen their technical skills and acquire interdisciplinary competencies (including project and time management, social and leadership skills), depending on the self-selected project task.

As an additional impact, the direct addressing of prospective young professionals in the engineering area and the strengthening of the network university-school can be considered. Positive effects on the motivation of the participants are apparent through insights into trend technologies, the possibility of putting the theoretical findings into practice, possible self-developed success experiences, e.g. [6,7] and the value of the social relevance of the summer school for the protection of young talent. Further positive aspects are expected with a view to the active design of the school-university transition (providing insights into technical innovations and possible fields of study, suitable role models, and attractive presentation of technical questions), e.g. [7].

The teaching-learning concept has been awarded the Teaching Award of the University and will be implemented for the first time in the summer semester of 2018.

B. Competencies in engineering in the course of digital transformation, its development and theory-based acquisition

In order to actively address (and to measure) competence developments, a clear understanding of competence is needed. In accordance with the underlying constructivist teaching conventions, e.g. [8, 9], the competence concept defined by Erpenbeck and Rosenstiel, in calling competencies „…dispositions of self-regulated acting" [10], is prioritized at this point.

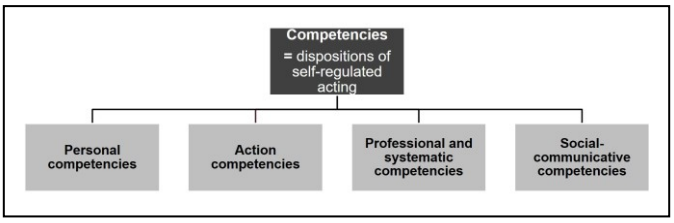

Fig. 2. Competence classes, according to [10]

A differentiation is made into competence classes (systematic, personal, action- and realization-oriented, and social-communicative competencies), to be seen in Fig. 2. These competences are further specified for the context of engineering, [11]:

- *knowledge processing* (strong engineering knowledge base, special engineering knowledge),
- *systematic competence* (e.g. project- and time-management; presentational competence, interdisciplinarity),
- *personal competence* (e.g. motivation, attitude toward learning and to incorporate into new branches, competence of self-reflection, responsibility and ethics as engineer, flexibility, the ability to work under pressure),
- *social competence* (e.g. cooperation competence, communication competence, leadership skills, conflict management),
- *practical competence* (e.g. ability to link theory and practice, capability to apply existing knowledge to solve newly arising problems).

In the course of the digital transformation, these competency classes will be further sharpened in terms of content and shifted in their weighting, e.g. [12, 13]. Thus, within the "professional and systematic competence" digital technical competence (here, among other things, the information and data competence, i.e. the challenge of preparing and evaluating ever larger amounts of data, and being able to deal with the associated increased complexity) has been integrated as a focal point, cf. [13]. Furthermore, the content orientation of personal and social competence is shifting under the influence of digitalization. In particular, the competence to act autonomously is regarded as essential in order to acquire further competencies, cf. [12]. In the future of more autonomous and sometimes virtual working environments, independent work, the ability to organize one's own work and prioritization is imperative, cf. [13]. Therefore, the self-responsibility belongs as well as the ability to communicate, networking competence and agility to the digital business competences, cf. [13]. These and other competence characteristics of personal and social competence (such as planning and organizational skills, cooperation skills, interdisciplinary working methods and the ability to work in international and diverse teams) are strengthened by digitalization in their relevance, cf. [5].

These competence requirements must serve as a starting point for the theory-based design of an engineering-based teaching concept with a focus on digitization. The aim of "Summer School 4.0: Digitalization" is therefore the promotion of professional and systematic competences in the field of digitalization, the acquisition of an active role of students in the learning process and to impart reflective digitalization competences. In addition to theoretical foundations and research findings from this area, theory-practice transfer plays a central role in the teaching-learning concept. At the same time, the course promotes the interdisciplinary competences

described above. This includes i.a. cooperation skills, communication and team skills in diverse teams, as well as self-organization skills and assumption of responsibility for one's own learning process (and passing on knowledge for others as well).

Furthermore, the theory- based development of the teaching approach goes back to the constructivist learning theories. These give prominence to the active learning process of the learner, e.g. [14, 6]. Further theoretical frameworks are gender theories focusing on STEM education, e.g. [15-17]. By looking at these theories, we see the requirements for a stronger link between theory and practice. These theoretical findings influenced the didactic learning concept and are presented in the following.

III. METHODOLOGICAL DIDACTIC DESIGN AND IMPLEMENTATION

A. Methodological Didactic Design of the Teaching Concept

The framework conditions extracted in Sec. II, such as active and self-determined actions of the students, the strong connection to the specialist science in connection with theory-practice-transfer, space for motivation and success as well as cooperative procedures, are implemented in the methodical-didactic design in the sequence: introductory phase, development phase, presentation phase und accompanying individual coaching, see fig.3.

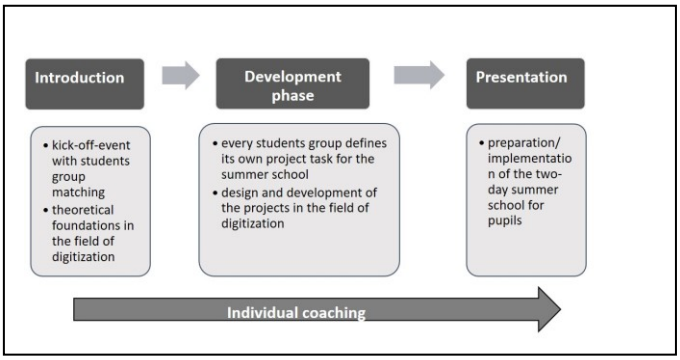

Fig. 3. Main phases of the Teaching-Learnig Concept “Summer School 4.0: Digitalization”

In the *introductory phase*, the scientific foundations for the topic of digitalization are worked out. While research findings of this subject area are presented by the teacher, the students' reflection on their impact on life and work is stimulated. Furthermore, the theory-based design of the teaching-learning concept for the summer school is developed in the entire group and a group assignment with a free choice of the respective project topic from the context "digitalization" is made. The aim of the free choice of topics is an increased identification with the topic and the active involvement of the diversity of the students. This methodological aspect is based on the self-determination theory by Deci and Ryan [6], which says that autonomy contributes to the experiences and enhancement of internal motivation. In the subsequent *development phase* (individual active group work in a free-time structure), in-depth subject content and methods are developed in accordance with the respective project theme, hands-on experiments are developed for the summer school and the content for the online learning platform is explored and incorporated. During this phase, the teacher will provide individual, continuous technical support to the learning process. The group results will be gathered in a workshop and prepared for the implementation of the summer school. The final *presentation phase* (implementation of the summer school) offers space for creative self-discovery and research based on the developed projects, which are worked on in tandem of students/pupils with the involvement of the online learning platform.

The didactic and methodological design implements a hybrid form of teaching that envisages a change between classroom teaching, individual teaching-learning phases and digital shares. In all phases an active interaction between the learners and the dialogical exchange between teachers and learners is anchored in the concept. Most intensively, the dialogical concept of education is addressed during the development phase. Through continuous support of group work and individual coaching by the teacher, mutual feedback and critical reflection of teaching and learning are facilitated. The strong theory-practice bond is a central element of the teaching-learning concept. All theoretically elaborated topics are practically implemented and enable the students to experience-based reflection on the theoretical foundations of digitalization. During the development phase, practical projects are developed and implemented to enable this targeted hands-on experience. This also applies to the theory-based concept development of the summer school, which is to be transferred to teaching practice. Thus, the students can have direct experience with the implementation of their concept.

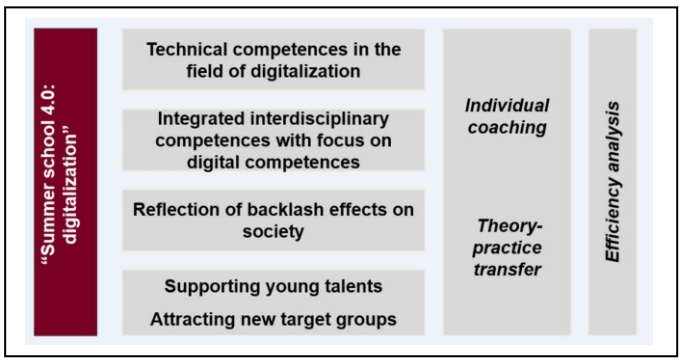

Fig. 4. Methodological Didactic Design of the Teaching-Learnig Concept “Summer School 4.0: Digitalization”

The active role of the students is anchored in the methodology and didactics of the teaching concept. Through the implementation of the project and practical phases as well as through the implementation of the summer school, the concept "do-it-yourself" is a central component. The students assume responsibility, both for the success of the summer school and, in a larger context, for the promotion of young talent. Throughout the course, the students will be closely accompanied by the teacher in their technical and interdisciplinary competence development. The possibility of "in-process feedback" of both the teachers and the students is

an important implementation quality in the summer school concept. In addition, feedback from students at the conclusion of the summer school can provide valuable input. The described methodology of the teaching concept is summarized in fig. 4.

B. *Curricular implementation of "Summer School 4.0: Digitalization"*

The module will be offered for the first time this summer semester. To actively address diversity and interdisciplinarity, the course is open not only for undergraduate students of engineering but also for other majors (business administration, psychology, education, environmental sciences) in order to involve all students and their respective subject culture. The targeted approach of diverse subject cultures is expected to generate synergies and exchanges that incorporate the respective perspectives, knowledge and methodological approaches into the concept development and implementation of the summer school. As described in Sec. IIIa, the students develop a concept for a summer school technique that presents the future field of our time "digitalization" and reflects its impact on society. During the subsequent two-day summer school in September 2018, the students work in tandem with approx. 80 students in grades 10 to 12 to expand on the action-oriented technical projects developed. Thus make another contribution to the assumption of social responsibility in the region by securing young talent in the field of engineering.

The benefit potential of digital teaching-learning formats is made possible by the already developed online learning platform. As part of the course, this online learning platform will be "filled with life" and used as a digital teaching-learning format during the summer school. The students prepare the thematic content of the summer school digitally and integrate it into the online learning platform. Under instructions, knowledge of programming and administration of websites (Wordpress) will be developed and a pool of materials will be created through the input of all project teams. In doing so, the heterogeneous knowledge and interests of the users should be addressed (application level: basic, application-oriented, and advanced). The online learning platform can be extended to current topics. Through online availability, all participants can follow up and deepen the content. A benefit for prospective students as "motivational material" would also be possible.

The concept is designed in such a way that it can be continued annually and that current trends and new topics within digitalization can be picked up.

IV. Research desing of efficacy analysis

The aim of the efficacy analysis is to survey the attractiveness of the summer school offer for the diversified group of students (and pupils) as well as to evaluate the contribution of the teaching and learning concept to the development of the students' professional and interdisciplinary competence. There is a need of evaluation instruments commensurate to the specific characteristics of the construct of competencies mentioned above, in order to gain findings and make statements on the efficacy of a competence-oriented teaching and learning approach. As a suitable instrument, the „HEsaCom", e.g. [18, 19], is applied to detect the increase in students´ knowledge processing. This inventory measures gains in competencies by students' self-reports and registers the following domains of competencies: *knowledge processing* (scale of 6 items, Cronbach´s alpha= 0.90), *systematic competence* (scale of 3 items, Cronbach´s alpha= 0.83), *cooperation competence* (scale of 5 items, Cronbach´s alpha = 0.87), *personal competence* (scale of 5 items, Cronbach´s alpha =0.85), *job-related competence* (scale of 5 items, Cronbach´s alpha = 0.85). Participants' answers were given on a five-point Likert scale (0= it doesn´t apply; 5=it´s completely true), see [18]. The category gender is used continually.

For the evaluation during the summer school both objective and subjective measurement procedures are used. As a mixed-method design quantitative and qualitative survey tools are used:

- *evaluation questionnaires:* the students as well as the pupils are being questioned at the beginning (measuring point *T1*) and at the end (measuring moment *T2*) of the summer school. Here, the „HEsaCom", e.g. [18, 19] is also integrated.
- *Participant observation* during the summer school with a semi-standardized observation grid. This contains open categories, incorporating several levels of analysis into the observation.

The empirical data to be collected should on the one hand serve to improve the concept. Furthermore, it can contribute to the research discussion on competence-oriented efficacy analyzes.

V. Summary and Further Development Steps

This work in progress paper introduces an innovative teaching approach to engineering education that addresses both subject and interdisciplinary competences in the context of digitization and includes reflection on backlash effects on society. First experiences with the implementation and results of the evaluation can be presented at the FIE Conference 2018.

Building on the experiences, improvements of the concept and the efficacy analysis will be conducted in the future. A further step is planned for the investigation of the influence of digitalization on the research landscape in the field of engineering education. Here, the categorization presented in Sec. I (fig. I) is to be extended to contributions from the FIE conference. The aim of expanding the scope of the survey is to provide more valid statements, an international perspective and the research-based derivation of potential key topics and trends in the area of digitalization.

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