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Adaptive E-Learning for the Engineering Design Education at Ruhr-University Bochum

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Abstract

Most lectures in the field of engineering are held in a traditional teacher-centred and frontal lecture format. This means that all students receive the identical information at the same pace without taking their individual skills, knowledges and competences into account. A didactic concept, that fosters an individual learning experience and digitally provides personalised learning materials for each student is Adaptive E-Learning. Within this paper the development of an Adaptive E-Leaning Environment in the course Engineering Design at Ruhr-University Bochum is presented.

Keywords: engineering design, digital learning, design education

1. Introduction

Engineers are key for the successful development of products, therefore engineering design related courses are part of the mechanical engineering curriculum, especially for undergraduate students (Albers *et al.*, 2012). Thereby the education of engineers faces new challenges (Kattwinkel *et al.*, 2018), e.g. fundamental courses such as lectures focusing on technical drawings are often attended by a large number of students (Metraglia *et al.*, 2011). Most of these students have differing levels of knowledge and experience caused by their various secondary education backgrounds, vocational trainings or completed pre-engineering courses (Kannengiesser *et al.*, 2015; Žeželj and Miler, 2018). Due to the large number of participants in first-year engineering courses, the most widely used course formats in design engineering in Germany are teacher-centred lectures and this will continue to be the case in the future (Albers *et al.*, 2012). So, all students are taught the same content at the same pace, even though they start at different levels of knowledge and competence. Additionally, due to the high number of participants, there is almost no interaction between the teachers and the students. Furthermore, students in large groups are inhibited to ask questions. (Pfäffli, 2015) Individual support to compensate the existing heterogeneity would require large tutor capacities (Eckert *et al.*, 2015). In addition, supplementary learning material has been shown to be quite useful in the engineering field for heterogeneous student groups (Žeželj and Miler, 2018). However, it is difficult for students to identify suitable material appropriate to their individual background and context and review available content on their own, especially during the transition from high school to college in the first-year courses (Arnold, 2015). Therefore, learning materials must not simply be provided, but have to be integrated meaningfully into the course concept (Arnold *et al.*, 2018). One approach to deliver personalised learning materials to students without creating immense workloads for tutors and teachers is the concept of *Adaptive E-Learning*. This can involve both individual and personal needs and preferences. (van Seters *et al.*, 2012; Rey, 2009).

Therefore, in this paper, the idea of an *Adaptive E-Learning Environment* for students in *Basic Engineering Design* is explained based on the following research questions:

- How suitable is the concept of an Adaptive E-Learning Environment for supporting the learning and teaching in the field of Basic Engineering Design education?
- How could the concept of an Adaptive E-Learning Environment be integrated into an existing course in the field of Basic Engineering Design education at the Ruhr-University Bochum?

To specify the understanding of the problem, the group of participating students is analysed in detail (section 2.1). As many university courses are based on *Constructive Alignment*, it is summarised (section 2.2) to understand the integration of an Adaptive E-Learning Environment in an existing course. The characteristics of an Adaptive E-Learning Environment are presented (section 2.3) to assess the suitability of an Adaptive E-Learning Environment for the analysed group of participants in existing Basic Design Engineering courses (section 2.4). With these findings an approach for the development of an Adaptive E-Learning Environment in a Basic Engineering Design course at the Ruhr-University Bochum is presented (section 3.2). Concluding the results are discussed and further work is suggested (section 4).

2. Problem specification and didactic basics

The basic problems of the first year students are specified to understand the problem of the heterogeneity in Basic Engineering Design courses (section 2.1). Afterwards the didactic concept of Constructive Alignment (section 2.2) and the characteristics of Adaptive E-Learning Environments (section 2.3) are presented in this section, in order to be able to assess the suitability of the integration of Adaptive E-Learning Environments in existing courses in the field of Basic Engineering Design.

2.1. Participating students in Basic Design Engineering education

First-year students face several challenges as they transition from high school to college. For example, students are not used to learn and study on their own and need guidance or specific assignments (Arnold, 2015). These challenges vary for different students (Brahm *et al.*, 2014), because they have different initial prerequisites due to their dissimilar previous school education and experiences e.g. in the applied learning methods, reached learning outcomes (skills, knowledge, etc.) and their accomplished form of graduation (Eckert *et al.*, 2015).

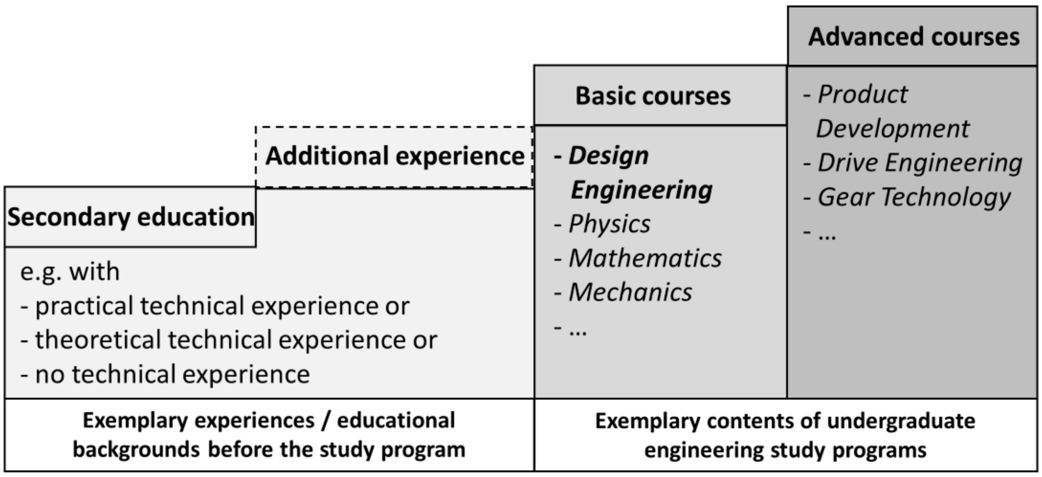

Figure 1. Basic Design Engineering in the educational career of German students

The different initial prerequisites are based on varying entry requirements, because next to attending different schools, students even have different educational careers in Germany. The access to a university is not only possible with a general matriculation standard but also with a lower form of graduate diploma and an additional vocational training with excellent grades, vocational baccalaureate

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or foreign matriculation standards. Furthermore, even in the same education career, subjects can be chosen and learning contents depend on the federal state educational system (Schindler, 2014).
This leads to the fact that some students gain a varying practical technical experience and theoretical technical experience or no technical experience. Next to the secondary education, students might gain technical experience by scholarships, any kind of additional vocational trainings, already graduated study programs or even personal interests e.g. in cars. So secondary education and additional experience cause differences in technical experience as illustrated in (Figure 1). All these students start together a study program involving design engineering e.g. *Mechanical Engineering* and have fundamental courses like *Basic Design Engineering*, *Mathematics* or *Mechanics*. After that, students specialise in advanced courses. Different international studies show the resulting consequences of the initial prerequisites in Basic Design Engineering education caused by differences in the individual technical experiences:

- Students with a vocational training or an advanced technical college certificate have already acquired a basic knowledge in manufacturing compared to students that start their studies right after their general matriculation standard or an equivalent graduation format (Žeželj and Miler, 2018).
- Students that attended pre-engineering courses have a different design cognition to those who did not participate in those lectures (Kannengiesser *et al*., 2015).
- Students from non-technical high schools need adapted motivational instruments and methodologies to raise their self-efficacy beliefs (Metraglia *et al*., 2015).

At the Ruhr-University a technical internship focusing on different manufacturing techniques such as. milling, grinding, drilling or welding is mandatory for every student and can be completed before the students begin to study (recommended) or in the course of their study program until the bachelor thesis. Besides the different educational backgrounds of the students, this is an additional reason why the group of participating students in Basic Engineering Design courses is very heterogeneous in technical knowledge and experience.

2.2. Constructive Alignment as a concept for university courses

Since the Bologna Process [1] and the resulting change in university teaching towards an outcome orientation, many courses are based on the didactic concept of Constructive Alignment (Baumann and Benzing, 2013).

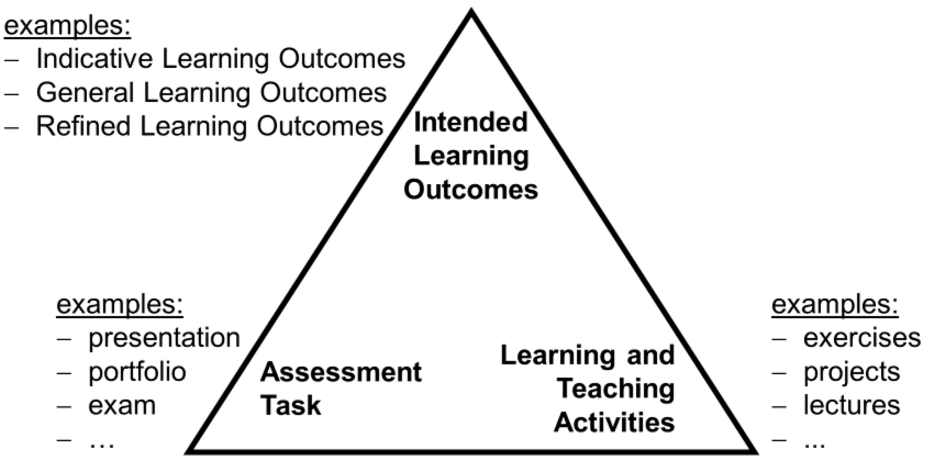

Figure 2. Concept of Constructive Alignment (Wildt and Wildt, 2011; Biggs and Tang, 2011*) with examples* (Biggs and Tang, 2011; Baumann and Benzing, 2013)

[1] Process for the Europe-wide standardisation of study programs

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This outcome based approach assigns teaching and assessment to Intended Learning Outcomes: (Biggs and Tang, 2011) and is suitable for several levels of study programs e.g. single lectures, whole modules or faculty profiles (Jungmann *et al.*, 2016). The three main elements are illustrated with examples in (Figure 2) and will be explained in detail:

- **Intended Learning Outcomes** are central in the system. These written statements explain what students are expected to achieve with which level of understanding and performance. The descriptions of these Intended Learning Outcomes are required for every study program, course or even learning unit and they indicate how students can handle the content or topic and in which context. For expressing these Intended Learning Outcomes is only one or at most two verbs used. (Biggs and Tang, 2011) Depending on the used verb in the Intended Learning Outcome Bloom classifies learning outcomes in six main categories of cognitive dimensions: *remember*, *understand, apply, analyse, evaluate and create* (Krathwohl, 2002). Learning outcomes are defined on mainly three different levels. *Indicative Learning Outcomes* describe complex and general learning outcomes. This level is used to detail full courses or even degree programs. *General Learning Outcomes* are more specific then indicative ones and address e.g. a single course unit. *Refined Learning Outcomes* align to the general learning outcomes and focus on specific knowledge and competences. They are used to describe the outcome of single *Teaching and Learning Activities*. They are formulated by the tutors or the students themselves and are directly testable. (Pfäffli, 2015; Mayer and Hertnagel, 2009)
- **Teaching and Learning Activities** describe the work students need to do for achieving the Intended Learning Outcomes. These Teaching and Learning activities include independent learning by themselves e.g. with exercises or in groups e.g. on projects, just like instructions by a teacher e.g. in lectures. (Biggs and Tang, 2011) The activities are arranged in a Learning Environment which encourage students to achieve the by the Intended Learning Outcomes addressed skills (Biggs and Tang, 2011). At the same time, students are different learning types, which makes different learning materials (audio files, pictures, etc.) for Learning Activities differently suitable for individuals (Vester, 2018).
- The **Assessment Task** reveals whether a student reached the criteria described by the learning outcomes. Every Intended Learning Outcome is examined with at least one item. The assessment directs the verb of the Intended Learning Outcome and takes differences in students' performances for classifying the degree of achievement (Biggs and Tang, 2011). For each learning outcome the appropriate form of assessment such as written or oral exams, presentations, portfolios or learning diaries have to be chosen (Baumann and Benstandadiing, 2013). When implementing assessments in E-Learning Environments, it is important to consider that not all levels of learning outcomes can be addressed by all kind of tasks. Lower cognitive dimensions (remember or understand) are easier to examine with so called closed question types like *Multiple-Choice*. (Mayer and Hertnagel, 2009). Depending on the examined learning it is differentiated between summative (at the end of a learning process) and formative (in steps during the learning) assessments (Arnold *et al.*, 2018). Whereas the overall performance of the students is often higher in a formative assessment due to the regular documentation and control of the individual learning performance. (Haas *et al.*, 2017)

2.3. Characteristics of Adaptive E-Learning Environments

E-Learning as an arrangement of digital learning media and virtual learning rooms (Arnold *et al.*, 2018) is efficient for large groups of students as it creates a reduced workload for the tutor (Schönwald, 2007). Furthermore, students can learn self-paced in many E-Learning formats (Arnold *et al.*, 2018), so the individual needed learning time of students is considered in this form of Learning Environment. The concept of an Adaptive E-Learning Environment takes further individual and personal needs and preferences into account instead of a standardised uniform Learning Environment (Rey, 2009). It is described as in interactive system, which adapts and personalises interactions between the system and the user and the presented learning content (Stoyanov and Kirschener, 2004).

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In general an Adaptive E-Learning Environment has different stages (Rey, 2009):

1. **An initial classification:** This classification can be carried out based on different criteria like preferred learning style, age or existing knowledge and skills (Rey, 2009; Niegemann and Heidig, 2019).
2. **The presentation of learning content and ongoing measurements:** Based on the initial assessment in step one, learners get learning content presented. The ongoing measurement can be continuous or intermittently. For the continuous measurement students' behaviour e.g. students' navigation in the system or facial expression can be captured. When testing intermittently knowledge tests or self-assessments are done repeatedly. (Rey, 2009) These steps are described as a loop of diagnosis and support (Fischer *et al.*, 2020). For the diagnosis the learning outcome needs to be defined on a granular level of small learning outcomes (Kerr, 2016). One option to measure these refined learning outcomes are closed question types e.g. Multiple-Choice. Thereby it is not only possible to analyse whether skills are available, but also a chosen wrong answer can indicate which skills or deficits students have. (Berger and Moser, 2020)

The different advantages of Adaptive E-Learning Environments are e.g. the prevention of students cognitive overloading (van Gerven *et al.*, 2006), a decrease of learning time (Rey, 2009), getting formative feedback of individual strengths and weaknesses (van Seters *et al.*, 2012), higher motivation of students (Kareal and Klema, 2006) caused by the fact, that the individual highest motivation can be reached, if the contents or tasks are moderately difficult for the student (Vollmeyer and Rheinberg, 2006). These advantages cause positive expectations in Adaptive E-Learning Environments (Rey, 2009), however the success of every Adaptive Learning Environment depends on its design (Liu *et al.*, 2017).

2.4. An Adaptive E-Learning Environment for Basic Engineering Design Education

The described problem of heterogeneous groups of students in Basic Design Engineering courses with different initial prerequisites of technical skills and knowledge caused by various secondary school education, vocational training or internships can be considered by an Adaptive E-Learning Environment. Every student can receive the individually needed learning content depending on their performance. The implementation in an E-Learning Environment offers the option to identify students existing skills knowledge and present content automatically. This is important to reduce needed personnel resources after an initial expense with the large number of participants in Basic Engineering Design courses. Next to the identification of existing skills and knowledge for the Adaptive E-Learning environment the test results can be used as a feedback for the teacher after a certain learning. They indicate students' skills and knowledge and the heterogeneity of the group or the overall level of learning in the group. This offers the opportunity to react with adapting the lecture e.g. with repeating a content many students had problems with.

As in Basic Design Engineering education courses with the frontal lectures as the most used format, the concept of an Adaptive E-Learning Environment seems to be a suitable approach as a lecture accompanying Teaching and Learning Activity in an existing course. The concept of Constructive Alignment does not only help to understand the integration of the Adaptive E-Learning Environment in an existing course but can also be used to develop learning units such as. an Adaptive E-Learning Environment.

3. Approach for the development of an Adaptive E-Learning Environment at the Ruhr-University Bochum

The aim of the idea of an Adaptive E-Learning Environment for Basic Design Engineering education is the development of a general and comprehensive concept to present students the individually needed Learning and Teaching Activities in an E-Learning Environment without any personal support by tutors. In the following chapter, the initial situation at Ruhr-University Bochum is generally and then specifically described in the context of Constructive Alignment (section 3.1). Afterwards the approach to develop a supporting Adaptive E-Learning Environment is presented (section 3.2).

3.1. Current situation at the Ruhr-University Bochum

Design Engineering A and *Design Engineering B* or in former times *Fundamentals of Design Engineering 1* and *Fundamentals of Design Engineering 2* are first year courses of the study programs *Mechanical Engineering* and *Sales Engineering and Product Management* at the Ruhr-University in Bochum, Germany. In the winter semester 2020/2021 nearly 400 students enrolled for the course *Fundamentals of Design Engineering 1*. The content of the course includes *technical drawing*, *dimensioning* and basics in *methodical product development*. The general Intended Learning Outcomes are specified in the module description. The course Assessment Task is a written exam at the end of the course (summative). Beside lectures and exercises with consultation hours, a lot of material for self-studying e.g. small online tests, books, videos etc. is provided in the online learning-management system Moodle (Moodle Contributors, 2021). Self-studying is recognised with 60 % of the overall course time expense. In (Figure 3), these specific didactic elements are allocated to the concept of Constructive Alignment.

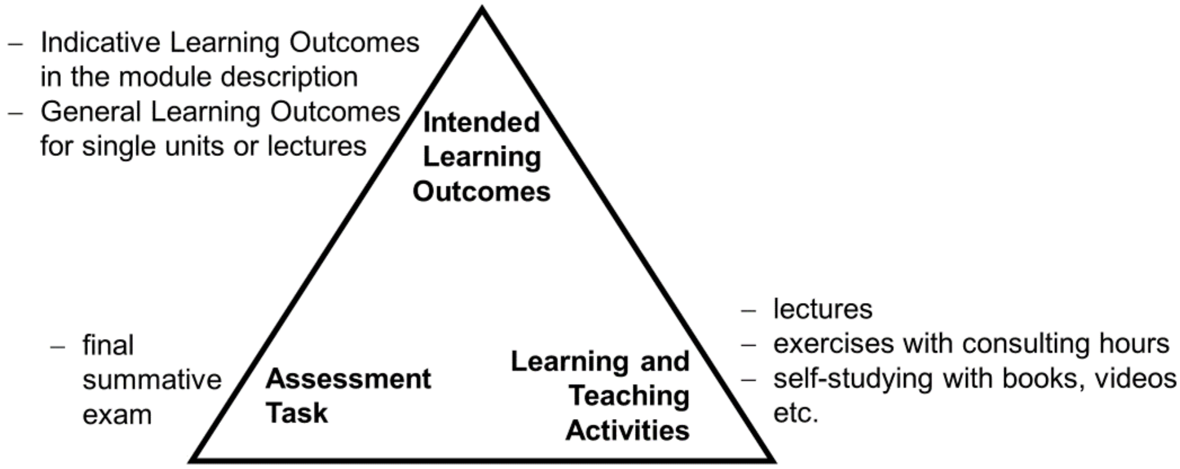

Figure 3. Course elements assigned to Constructive Alignment of the existing course Engineering Design A at Ruhr-University Bochum

3.2. Development of an Adaptive E-Learning Environment

In the course Design Engineering A, a traditional teacher-centred lecture, all students receive the identical content in the same pace either in presence at the university or in online synchronic lectures. However, not all students reach the Intended Learning Outcomes of the course with this teaching format, partially due to their different technical knowledge and experience. For that reason, for the winter semester 2022/2023 an Adaptive E-Leaning Environment will be developed for this course. Adaptive E-Learning is expected to present students individually needed learning material in their self-studying time, instead of only literature lists and examples in the Moodle course. So, it will be an additional offer for the students next to the lectures and exercises with consulting hours. Students will then have the chance to evaluate to what extent they have achieved the specific learning outcomes (e.g. of a learning unit) by taking small diagnosis and assessment tests at home. Based on the results of these regular tests, the students will receive individual recommendations for different learning contents (e.g. tutorials for technical drawings or additional worksheets for bolt calculations) for their self-study time at home. (Figure 4) demonstrates the planned concept of the Adaptive E-Learning Environment, in which students participate in the same general lectures and then study individually according to their needs and prerequisites at home.

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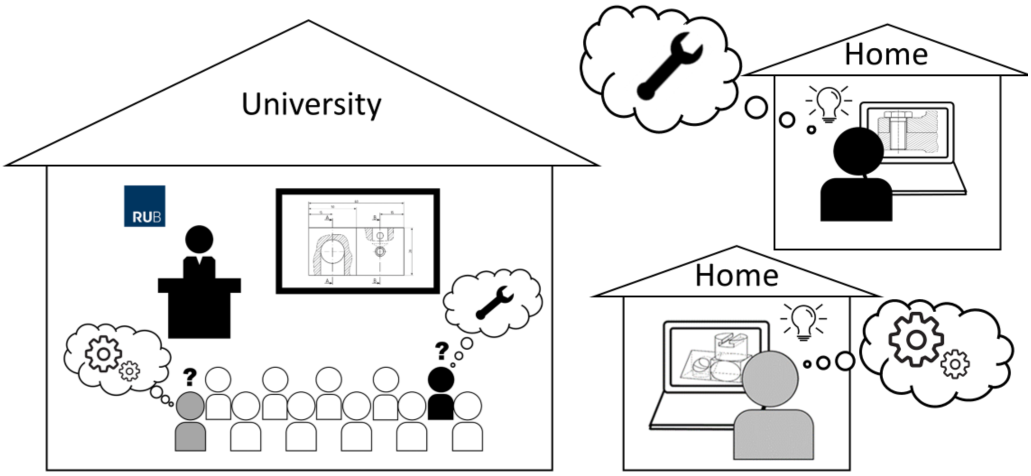

Figure 4. General idea of the application principle of an Adaptive E-Learning Environment at the Ruhr-University Bochum

Because Moodle is already widely used at Ruhr-University Bochum, as a learning-management system, the Adaptive E-Learning Environment will be implemented in Moodle as a pilot project.
The lecture accompanying Adaptive E-Learning Environment with the presentation of appropriate learning activities has to be integrated in the whole course concept based on the existing elements in accordance with Constructive Alignment. As Constructive Alignment is suitable for the development of several levels of study programs e.g. single lectures, whole modules or study programs the Adaptive E-Learning Environment is also developed based on it as illustrated in (Figure 5). For this purpose, the three elements of Constructive Alignment for the development of the Adaptive E-Leaning Environment for the course Engineering Design 1 are defined in the following main steps:

1. The first step is the refinement of the general Intended Learning Outcomes as described in the module description into refined Intended Learning Outcomes for the Adaptive E-Learning Environment. Thereby these refined Indented Learning Outcomes must be automatically testable with the options offered by the learning-management system Moodle. The detailed consideration of all learning outcomes of the individual learning units and their clustering into topics or application examples makes weekly testing appropriate.
2. The second step is the creation of tasks for identifying existing skills and knowledge as weekly formative assessments. The aim of the tasks is not only to determine the degree of achievement of the learning outcomes, but also to identify existing deficits, in order to provide appropriate support. The technical implementation in Moodle will accomplished with closed question types e.g. multiple or single choice in the function *test* and a feedback for the chosen answer. Thereby the distractors will be chosen carefully to indicate a specific deficit of a skill needed to reach the Intended Learning Outcome. This can be demonstrated on the following example: The refined Intended Learning Outcome is: "Students can apply the approach for the determination of the maximum fitting clearance". For reaching this, students need e.g. to know the position of the tolerance zones, find and read out the size of the tolerance zones or apply the calculation of the upper dimension. These are used for developing the distractors, so students will receive differentiated feedback on exactly what they have done wrong. A continuous assessment will be included by the integration of tasks from former weeks. Furthermore, content that is not explicitly addressed but is required for the further Intended Learning Outcomes is examined (e.g. geometric area calculation).
3. The third step is the assignment of available learning materials (book chapters or paragraphs, learning videos, lecture sheets etc.) to learning levels diagnosed with the test results for providing individual support to reach the Intended Learning Outcomes. These learning materials will be presented as links in the feedback of the single questions and also the whole test. All materials for the learning activities will be available in the course and are visible for all students, the Adaptive E-Learning environment only suggest them.

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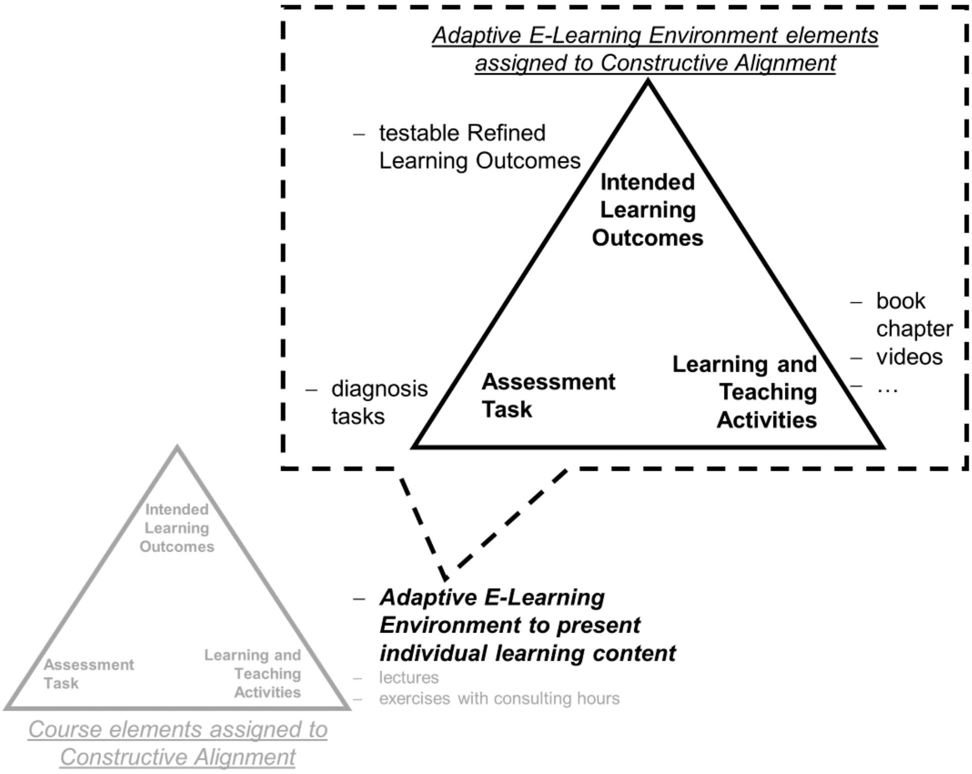

Figure 5. Concept of an Adaptive E-Learning Environment based on constructive alignment and the integration in an existing course

4. Discussion and outlook

In this paper the suitability of the didactic concept of Adaptive E-Learning Environments for the field of Basic Design Engineering is discussed and an approach for applying it in an existing course is presented. An Adaptive E-Learning Environment delivers personalised learning materials to students considering both individual and personal needs and preferences without creating immense workloads for tutors and teachers. The students of first-year Engineering Design courses have varying initial skills and technical knowledge e.g. due to different secondary education. However, individual support to compensate the existing heterogeneity is only slightly present, because the most widely used course format in Design Engineering in Germany are teacher-centred lectures. So, the concept of an Adaptive E-Learning Environment seems to be suitable for Basic Engineering Design education. The integration of the Adaptive E-Learning Environment as a Learning Activity within an existing course according to Constructive Alignment is presented. In addition to the integration in the existing course the main elements of the Adaptive E-Learning Environment itself are developed according to Constructive Alignment in the presented approach. This will be implemented in Moodle for students participating in the course *Design Engineering A* in the winter semester 2022/2023 at the Ruhr-University Bochum. After the implementation the Adaptive E-Learning Environment needs to be evaluated to see if students with different initial prerequisites find it helpful for their self-study time and improve their exam results. The adaptivity of the presented concept focuses on thematic knowledge and skills. With a detailed investigation of the initial technical skills and knowledge of the participants the criteria of adaptivity could be improved. Different learning types or preferences of the students are not taken into account, although this consideration would also be necessary for maximum learning success. Furthermore, the concept is only adaptive with testing the knowledge intermittently and suggesting content based on these test results. Continuous adaptivity e.g. by capturing the navigation would need different software solutions and could be taken into account in the future. The presented concept has the advantages of a formative assessment e.g. regular documentation and control of the individual learning performance or preparation for online exams.

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Because of the implementation in Moodle the options of automatic assessments are limited, which cause the problem that Intended Learning Outcomes on higher taxonomy levels cannot be tested. The examination of Intended Learning Outcomes on higher taxonomy levels would require the integration of further software approaches, as shown by (Hoppe *et al*., 2021), for example.

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