INDIVIDUALIZATION IN ENGINEERING DESIGN EDUCATION: IMPLEMENTATION OF AN ADAPTIVE E-LEARNING ENVIRONMENT (ADE-LE)

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ABSTRACT

Well-educated engineers are key for successful engineering design in product development. Due to varying school education and technical backgrounds, the students have different prerequisites for the acquisition of competences. Subject of this paper is to show the methodical implementation of the prototype AdE-Le suited to the curriculum at Ruhr-University-Bochum and the open source learning platform Moodle. Aim is to evaluate the didactic potential to support engineering students with heterogeneous competence levels. The general needs and existing approaches for E-Learning environments as a means to individualize learning content in engineering design are discussed. Major aim is to reduce the linkage between the students' technical background and their exam success. AdE-Le as an exemplary application is developed based on the didactical concept of Constructive Alignment. Due to a harmonization of learning methods and contents in Engineering Design across the members of the Scientific Society for Product Development the results of this investigation can be transferred to other Universities.

Keywords: Design engineering, Design education, Education

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1 INTRODUCTION

Well-educated engineers are key for successful engineering design in product development. Therefore, engineering degree programmes include many design-related subjects, especially in the first semesters. (Albers *et al.*, 2012) However, the education of engineers faces new challenges (Kattwinkel *et al.*, 2018). One is the overall increase in student heterogeneity with regard e.g. to motivation and learning competences due to educational expansion (Eckert *et al.*, 2015). Another challenge is related to the divergence with regard to technical background and experience of the students (Žeželj and Miler, 2018; Metraglia *et al.*, 2015b; Kannengiesser *et al.*, 2015). Especially in Germany, a wide range of school-leaving qualifications or occupational educations can entitle to enrol for a university degree in engineering (Kossack *et al.*, 2022). Also the extent to which internships (must) have been completed before starting University influences student's ability to cope in an engineering design course (Kossack and Bender, 2022). The dominant teaching format in engineering design at universities is teacher-centred in Germany (Terkowsky *et al.*, 2018; Albers et al., 2012). Thus, regardless of technical background, all students are exposed to the same learning content, taught at the same pace. In addition, the group size and the teaching format promote little interaction between teachers and students. The group size in particular inhibits students from asking questions in plenary. (Pfäffli, 2015) Reducing the size of learning groups for individual support is often not possible due to personal resources (Eckert *et al.*, 2015). Therefore, in addition to the frontal lecture formats, self-study is inherent in teaching product development in higher education (Wissenschaftliche Gesellschaft für Produktentwicklung WiGeP e.V., 2018). This implies that additional learning material in engineering design education for self-learning phases is helpful for heterogeneously prepared student groups (Žeželj and Miler, 2018). However, it is particularly difficult for first-year students in the transition from school to university to organise these self-learning phases and to identify individually suitable material (Arnold, 2015a). An additional pronounced personal learning competence, i.e. the ability to reflect on, plan, design and evaluate one's own learning, is in general required (Arnold, 2015b). Again, these learning competences vary greatly due to the general student heterogeneity (Brahm *et al.*, 2014). So learning materials must not simply be provided, but have to be integrated meaningfully into the course concept (Arnold *et al.*, 2018). Against this background, the development of an adaptive learning environment for automated individualized suggestion of learning content in the self-study phase has been proposed for engineering design education (Kossack *et al.*, 2022). In order to assess the extent to which an adaptive E-Learning environment facilitates the acquisition of competences for the students as a whole and leads to a homogenisation of knowledge among the student group, implementation and evaluation is necessary. Subject of this paper is to show the methodical implementation of AdE-Le, an E-Learning environment prototype suited to the curriculum at Ruhr-University-Bochum into the open source learning platform Moodle and its evaluation with regard to the didactic potential to support engineering students. The results are discussed and further steps on the integration in engineering curricula elaborated.

2 THEORETICAL BACKGROUND AND STARTING POINT

AdE-Le is an adaptive E-Learning environment developed to accompany a first-year course on engineering design at Ruhr-University Bochum. As a target group the students are heterogeneous both with regard to their technical expertise as well as their capability of coping with teacher-centred lectures which is elaborated in section 2.1. Based on this, general basics and existing E-Learning approaches are presented and exemplary use cases for adaptive learning systems are briefly summarized in section 2.2. E-learning in the field of engineering design education with focus on individualization is detailed in section 2.3.

2.1 First-year students in engineering design education: differing technical expertise and capability to cope with teacher-centred lectures

In general, first-year students face several challenges as they transition from high school to university. They are mostly not used to study autonomously or organise their self-study time. Also, they have difficulties identifying appropriate learning material for their own performance level. (Arnold, 2015a) This indicates insufficient self-learning competence, i.e. the ability to organise, plan and reflect on one's own learning (Arnold and Tutor, 2006). These challenges vary among students (Brahm *et al.*, 2014) and

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depend on previous educational pathways (Eckert *et al.*, 2015). For instance, in Germany, access to a university is possible with a general matriculation standard, but under specific conditions also with a graduation from a technical college or a vocational training with excellent school grades, vocational baccalaureate or foreign matriculation standards. Furthermore, even in the same education career, learning contents depend on the federal state educational system and subjects can be chosen individually. (Schindler, 2014) These conditions make the targeted group of students very heterogeneously from a teaching point of view. The subject matter addressed here is technical drawing. In engineering design, the solution to a technical task is developed. This includes the activities of representing ideas, e.g. on sketches, and the detailing of the ideas through design and design calculations, as well as the final clear description of this solution with e.g. technical drawings. This makes technical drawing fundamental for engineering design education. (Conrad, 2019) Especially manual drawing (sketching) is often taught in the first semesters of higher education courses not only as a means to document technical concepts, but also as a basis for the creation of CAD models (Metraglia *et al.*, 2015a). In the teaching of technical drawing, the following observations have already been made regarding the influence of prior education on the development of competences:

- Students with an internship, technical education or technical school certificate have basic knowledge of manufacturing processes compared to general school certificates and thus have an advantages in technical drawing (Žeželj and Miler, 2018).
- Students without a technical school certificate need adapted support in technical drawing in higher education (Metraglia *et al.*, 2015b).
- Students who have participated in engineering pre-courses have a better spatial imagination than those who have not participated (Kannengiesser *et al.*, 2015).

Based on these findings a detailed investigation by means of a student survey and statistical data analysis was carried out in engineering design education at the Ruhr University Bochum. A first-year course for basic engineering design education was selected in order to investigate the problems outlined in the introduction. The course comprises approx. 50 % presence learning phases in large groups (up to 250 students) and 50 % self-learning phases. The content of the course includes technical drawing, dimensioning and basics in methodical product development. The results of the survey showed, that some 40% of the students had technical expertise from internships - focussed on basic manufacturing techniques such as milling, grinding, drilling or welding - as required in engineering courses or earlier vocational trainings. These technically more experienced students on average rated the scope of the lectures and the degree of difficulty as lower compared to their technically inexperienced fellow students. They also completed the module after one year of study with statistically significant better grades. The students with previous technical education also considered their experience at least partially helpful. In addition, according to their own statements, they lacked less background knowledge in the frontal lectures than students without previous technical training. Furthermore, all students felt that they only occasionally or rarely found tasks suitable for their individual level of performance for their self-study time and that they were only partially able to work independently on content that they had not understood during the lecture.

These findings verify the student's difficulties with the organisation of the self-study phase. It has been deduced from this that the courses offered are not sufficient to homogenise the knowledge of the student group, especially since it is shown that students in the transition from school to higher education may not be able to make sufficient use of the self-learning phases and consultation hours provided for in the curriculum because they have acquired too little self-learning competence. (Kossack and Bender, 2022)

2.2 Adaptive E-Learning

Overall, digital teaching and learning scenarios are considered an improvement for higher education teaching (Handke, 2020). Characteristic opportunities are time- and location-independent learning as well as a self-directed learning pace. Compared to frontal classroom learning or synchronous online events, E-Learning therefore holds the potential for an individualization of the learning process. (Arnold et al., 2018) Research on E-Learning in the field of engineering design has greatly increased due to the pandemic driven digitalisation. Didactic concepts that have been implemented are for instance project-based learning, blended learning, gamification, as well as the development of automated evaluation options or new visualisation concepts (Kossack and Bender, 2022).

Adaptive E-Learning is a didactic approach for the individualization of the learning environment with regard to the individual needs and preferences of the user. An initial learning environment is presented to

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the user based on an assessment. During use, further measurements of the learning content or learning characteristics are made in order to bring about a constant modification of the learning environment. (Stoyanov and Kirschener, 2004; Rey, 2009; Kerr, 2016) 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 personalizes interactions between the system and the user and the presented learning content (Stoyanov and Kirschener, 2004) and is divided into the steps of initial classification and the presentation of learning content with an ongoing measurement (Niegemann and Heidig, 2019; Rey, 2009). The ongoing measurement can be e.g. capturing students' navigation or testing knowledge intermittently (Rey, 2009). Some exemplary approaches are given for different subjects in Prusty and Russell (2011), Fidalgo-Blanco *et al.* (2014), Rusak (2017), Kolekar *et al.* (2018) or Kolekar *et al.* (2019). Key findings applicable for the AdE-Le are referred to in the following chapter.

Existing E-Learning approaches in engineering design education hardly take individualization into account so far. One approach for the development is presented (Kossack et al., 2022), but it is focused on the didactic integration and not evaluated to what extent the use of an adaptive E-Learning environment leads to a homogenisation of the student group and if the students find this approach helpful. Adaptive E-Learning systems in other subjects confirm typical advantages of adaptive learning support, but are not focused on differing initial prerequisites. The technical implementation is often in focus.

2.3 Constructive alignment as basis for an E-Learning environment

An approach for the integration in an existing course concept based on Constructive Alignment is presented in (Kossack *et al.*, 2022). Constructive Alignment is an outcome based approach assigning Teaching and Learning Activities and the Assessment Task of the learning results to Intended Learning Outcomes (Biggs and Tang, 2011). It is suitable for several levels of study programs entire degree programs, courses or single lectures (Jungmann *et al.*, 2016). The Intended Learning Outcomes (ILOs) are key in the system and explain what students are expected to achieve with which level of performance and understanding (Biggs and Tang, 2011). Depending on the used verb in the ILO Bloom classifies learning outcomes in six categories of cognitive levels: remember, understand, apply, analyse, evaluate, and create (Krathwohl, 2002). ILOs can be defined on different levels of detail e.g., for full course programs or for single teaching or learning activities (Pfäffli, 2015; Mayer and Hertnagel, 2009). Teaching and Learning Activities describe the work students need to do for achieving certain ILOs. The connection between Intended Learning Objectives, Learning Activities and Assessment Tasks in general and applied to AdE-Le is shown in figure 1. Exemplary Teaching and Learning Activities are participating in lectures, watching a learning video at home, working on a project in a group etc. The Assessments Task reveals whether a student reached the ILOs. (Biggs and Tang, 2011) Assessment Tasks need to be aligned with the ILOs and are for example written or oral exams, portfolios, presentation etc. (Baumann and Benzing, 2013). The suggested approach allocates AdE-Le as a Teaching and Learning Activity in addition to lectures, exercises and consulting hours.

Since AdE-Le is to accompany an existing lecture, it must be integrated in the whole course concept, based on the existing elements in accordance with Constructive Alignment (see figure 1). The elements of Constructive Alignment for the development of the AdE-Le accompanying the existing first-year course *"Engineering Design A"* of Ruhr-University Bochum were defined in the following main steps (Kossack *et al.*, 2022):

1. Break down the overall ILOs of the course as described in the module description (course catalogue) into refined ILOs for the AdE-Le.
2. Create Assessment Tasks as diagnosis tasks to evaluate existing skills and knowledge of students. The limitations of automated testing in E-Learning must be taken into account: the type of question is related to the competence to be assessed. In the case of closed questions (yes/no), i.e., questions with a limited number of selection options (e.g. single or multiple choice), often only lower cognitive levels (e.g. "remember" or "understand" in Blooms taxonomy) can be addressed. (Mayer and Hertnagel, 2009) However a careful choice of distractors (wrong answer options) helps to identify exiting deficits (Berger and Moser, 2020).
3. Assignment of available learning materials (book chapters or paragraphs, learning videos, lecture sheets etc.) to identified learning levels as diagnosed with the test results from 2 for providing individual support with recommended Teaching and Learning Activities.

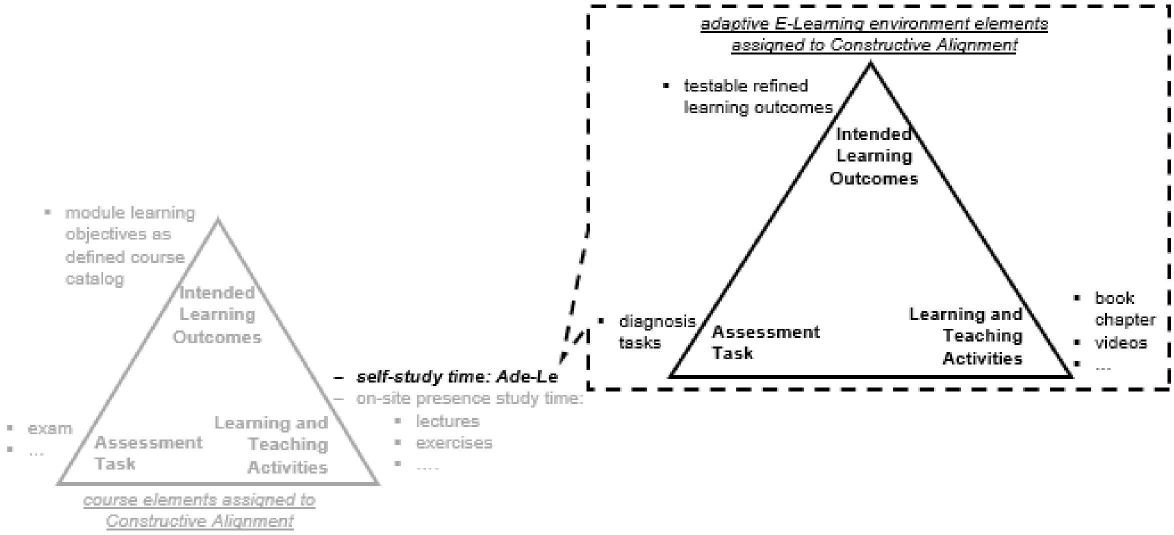

Figure 1: Integration of the AdE-Le in an existing course concept (Kossack et al., 2022) according to Constructive Alignment (Biggs and Tang, 2011; Wildt and Wildt, 2011)

3 DEVELOPMENT AND IMPLEMENATION

In order to assess the effectiveness of an adaptive E-Learning environment for knowledge heterogeneous student groups in engineering design education, an exemplary implementation is needed and presented for the conditions at Ruhr-University Bochum (section 3.1). This implementation of AdE-Le is based on an existing approach to development along the Constructive Alignment and the experiences of implementations in different subjects are taken into account. Finally, the evaluation criteria and data collection are presented (section 3.2).

3.1 Conditions in the engineering design education at Ruhr-University Bochum and the implementation of Ade-Le in Moodle

The implementation of AdE-Le was elaborated for the first-year university course in engineering design "*Konstruktionstechnik A"* at the Ruhr-University in Bochum. The content of the module comprises technical drawing, calculations and basics of methodical product development. In winter semester 22/23 some 400 participants enrolled. Students of the courses *Mechanical Engineering* and *Sales Engineering and Product Management* participate in the teacher-centred lectures and exercises with consulting hours. For students of Mechanical Engineering only a technical internship dealing with the basics of existing manufacturing processes is recommended to be completed before starting the studies. The activities in this internship can vary strongly depending on the facilities and the supervision on-site.

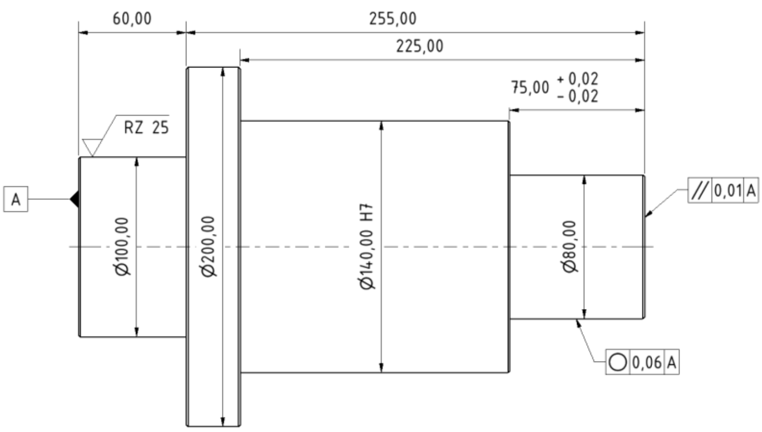

Figure 2: Typical assessment task

Ruhr-University Bochum uses learning management system Moodle so this is also applied in the "Konstruktionstechnik A" course for providing documents and distributing information on lectures and exercises. The development of an adaptive learning environment as a supplement to lecture and

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exercise for the self-study phase and is based on the approach of constructive alignment presented in section 2.3. The general idea is, to grade the knowledge and competences of the user and recommend based on this answer appropriate individual learning content.

In this section the AdE-Le environment for dimensioning, tolerances and fits is described exemplarily. Firstly, the intended learning outcomes for AdE-Le are defined. These are refined learning objectives from the module description in the course catalogue and take the assessment task into account. The learning objectives in the module description are rather general and not related to concrete use cases. In order to integrate the learning activities of AdE-Le best into the whole module according to Constructive Alignment, the use cases are selected in accordance with the required examination performance. An exemplary assessment task is the technical drawing including tolerances and surface details of a shaft as illustrated in Figure 2. The students are asked for appropriate dimensioning and tolerancing suitable for manufacturing. The correct answer requires the understanding of manufacturing, in this case the turning and milling processes. The refinement of one learning objective with taking the assessment task into consideration is illustrated in table 1. All refined learning outcomes are exemplified for the students at the beginning of each activity in AdE-Le.

Table 1: Exemplary refinement of Learning Outcomes

module learning objectives as defined in course catalogue	**exemplary refined learning outcomes for the adaptive e-learning environment**
Students can dimension and tolerance selected technical components in accordance with standards and apply/determine fits and standards in order to produce standardised general and drawings for production.	Students can calculate and select fits.
	Students can apply rules for dimensioning.
	Students can describe the manufacturing of components using turning and milling processes.
	Students can use different symbols to indicate shape and position tolerances.
	Students can use dimensional tolerances.
	Students can read and select general tolerances.

For the implementation, mainly the Moodle function "*Activity Lesson*" is used. This enables the combination of pages on which content is included and pages for branching or with questions. For each page created, jumps to following pages are defined depending on the user's behaviour. The second step in the development is the creation of related question tasks. The navigation in AdE-Le is based on the chosen answers to these questions.

Specific feedback is prepared and stored for each individual answer option. In the Activity Lesson, the learning contents that are assigned to the individual user answers of the diagnostic test are integrated as directly as possible. For example, videos or interactive content in H5P format [1] are embedded directly into the pages. But also book chapters or DIN standards are recommended, but not integrated in the system. The number and format of recommend learning content depends on results of the assignment in step 3 of the development. Individual recommended learning contents are mostly broken down into micro-learning units of 4-5 minutes, as recommended by Rusak (2017). Figure 3 illustrates the concept of the Activity Lesson. The student chooses an answer and the AdE-Le gives feedback and usually recommends learning content. These questions tasks test the refined learning outcomes and require, for example, selecting from a given set of solutions the correct symbolism for a shape tolerance or selecting the correct position for the symbol. In principle, the aim is to refine the learning outcomes until these can be checked automatically. However, since higher taxonomy levels of ILOs are very difficult to test with closed question types, tasks are also integrated in which students receive a sample solution and guidance on how to assess or grade their own solution. After that, they have to choose based on their own findings the next page as appropriate for them. In addition, self-assessment questions are also integrated for diagnosis. These are intended to help students reflect on their own learning process and develop an advanced self-learning competence, e.g. "Could you describe how the component shown is manufactured?". Furthermore, individual preference are taken into account by asking e.g. "Would you like to learn more about testing equipment like external screw-type micrometre or vernier caliper?". Depending on the question and the answer after using the

[1] Software for developing interactive content e.g. presentation and videos (H5P Contributors 2022).

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recommended learning content, e.g. a video, the student will be re-directed to the initial question and has a new chance to answer (see answer 1). By choosing answer 3 the students get different feedback and different learning content is recommended, e.g. a book paragraph, but will after that jump to the next question. In fault finding tasks, there is often another question before feedback to find out what the student means exactly and then give differentiated feedback. To cater for different learning styles, multiple learning materials are provided where possible, so students can decide for themselves whether they prefer to read, watch a video or work with an interactive content.

The time and number of steps students spend in the AdE-Le depends on their competences. Students who are far away from reaching the ILOs of AdE-Le need a lot of content to achieve the ILOs and might be going back to the same question several times until they answer them correctly (see figure 3 choosing answer 1). In contrast to this, students who already achieved the ILOs of the AdE-Le get a feedback and jump to the next question. Nevertheless, even with only correct answers, tasks are suggested for exercise. Reaching the end of an activity is visualised for each student throughout the course and leads to the activation of more new activities.

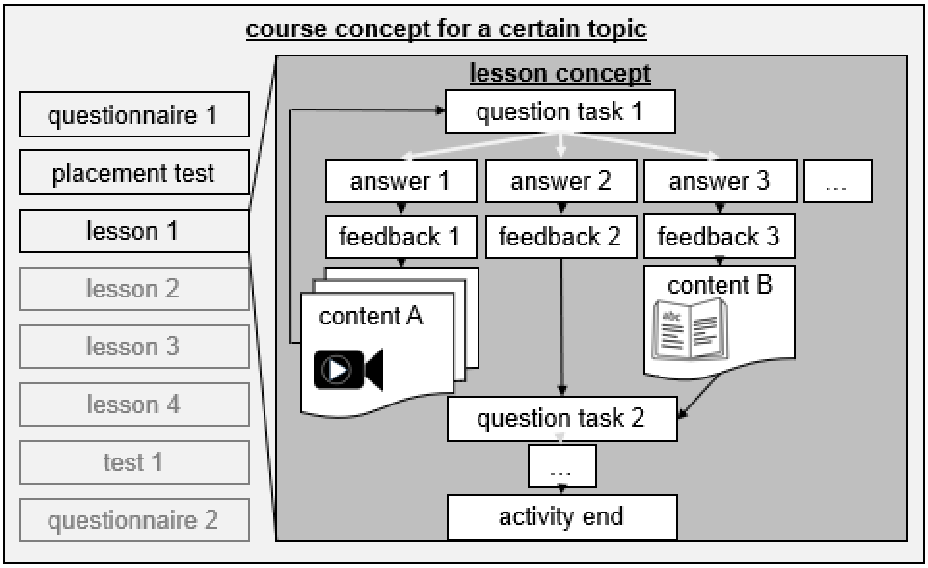

Figure 3: Course concept with detailed lesson concept

The types of question in the Activity Lesson are limited. In order to be able to use further Moodle functions, e.g. the *"Activity Test"*, a further adaptivity within the course is created by prerequisites between the different activities. The Activity Lesson 1 in figure 3, for example, is only activated when the placement test has been passed with at least 70 % correct answers. The Moodle function Activity Test offers the advantage that questions are selected at random and therefore students receive different questions when they repeat the activity. Furthermore, STACK[2] questions can be used to store mathematical formulas and thus check multi-step calculations. In the presented example a placement test is needed to start with four adaptive learning units and implemented with the Activity Test. This test checks previous learning outcomes on spatial abilities and correct drawing views of components, because without achieving these, it is not possible, for example, to select views in which all geometries can be correctly dimensioned. For the topics dimensioning, tolerancing and fitting tolerances four lessons are implemented. The first lesson deals with dimensioning and tolerancing rules in general. The second lesson addresses different types of tolerancing and dimensioning (for function, for manufacturing, for testing). A lot of recommended content are e.g. videos showing how components are manufactured. The third lesson thematises Fitting, shape, and positional tolerances. The fourth lesson addresses fittings. Due to the limitation of the activity lesson the calculation for the topic fittings is supplemented with an activity test. The activities do not have to be completed in a given order. However, certain activities are prerequisites for others. For example, lesson 1 needs to be

[2] Open Source System for computer based assessments in mathematics (Moodle Contributors 2022).

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completed to unlock lesson 2, lesson 3 and lesson 4. Test 1, however, is only unlocked after completing lesson 4.

3.2 Evaluation: preliminary results, further opportunities and plans

Two questionnaires are integrated in AdE-Le (cf. figure 3). The first questionnaire is required to start the learning units and asks about an existing technical background, to what extent there are current difficulties in organising the self-study phase and how difficult the module is currently perceived to be.

It is shown that the students surveyed this year face the same challenges due to the transition from school to university as presented in 2.2. Furthermore, the group of students has the same high variety in technical experience. Even students with the "same" technical background e.g., a technical internship have gained different experience though them e.g., understanding a turning process or reading a technical drawing. The second questionnaire is activated if all adaptive learning units have been completed. This test uses various items to ask if the students find it helpful in general with similar items as Prusty and Russell (2011) e.g. motivation and help to understand the content in the lectures and especially to what extent AdE-Le has facilitated the organisation and purposeful utilization of the self-study phases. In addition, the same questions as in test 1 are asked about the current perception of the level of difficulty of the course to see if the same students perceive a course easier with this additional E-Learning support. 106 students finished all activities and submitted the feedback questionnaire. It can be provisionally summarised that students spent more time on the self-learning phase through the adaptive learning units than without them, and that the self-learning units were motivating to deal with the content outside of the classroom learning phase. In addition, the students found the feedback on their own learning status very helpful and thought that the suggested learning content was mostly very well suited to their current learning status. The detailed data analysis is still pending and will be presented in detail in a further publication. Further data evaluated are the correlation of AdE-Le, students' technical background and the exam grade. These will be compared in particular with the statistical results of the survey detailed in 2.2 as these are taken in the same course. This allows to assess whether this kind of adaptive learning units makes it easier for students to acquire competences overall and whether students with prior technical knowledge perform better in examinations to the same extent as students without prior technical knowledge or whether the adaptive learning environment leads to an overall increase in knowledge

4 DISCUSSION AND OUTLOOK

This paper discusses the general needs and existing approaches for E-Learning environments as a means to individualize learning content in engineering design. AdE-Le as an exemplary application for engineering design education at the Ruhr-University Bochum is conceptualized based on the didactical concept of Constructive Alignment. Due to the framework conditions at Ruhr-University, AdE-Le is implemented in the learning management system Moodle which determines the technical options compared to existing approaches in other degree programmes. Here, the adaptivity is created by grading the user's competence for a specific content based on a choice of answer options in the so-called "Activity Lesson" and through entry requirements for dedicated activities within the tool. With this implementation, it is possible to investigate the benefit of such an E-Learning environment to support the self-learning phase in the acquisition of engineering design competences. Major aim is to reduce the linkage between the students' technical background and their exam success.

The results of the evaluation are outstanding but will be available after the final module examination in March 2023. However preliminary investigations indicate a positive correlation between the usage of the tool and success during lectures and exercises depending on technical background. If these results will be confirmed in the final evaluation general improvements based on the evaluation results and especially further technical possibilities and tools will be implemented. This can relate e.g. to expanding the limited possibilities of the question types especially for higher taxonomy levels (e.g. the approach of Hoppe et al. (2021) or to automatically take into account different types of learners (cf. (Kolekar et al., 2019)). Further adjustments for other contents covered in the course such as methods of projection, dimensioning different machine elements (bearing, screws etc.) will then also be elaborated and evaluated based on the existing results. Due to a harmonization of learning methods and contents in Engineering Design across the members of the Scientific Society for Product Development (Wissenschaftliche Gesellschaft für Produktentwicklung WiGeP e.V., 2018) the results of this investigation can be transferred to other German Universities.

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