POTENTIAL OF ADAPTIVE E-LEARNING FOR KNOWLEDGE HETEROGENOUS GROUPS OF STUDENTS IN ENGINEERING DESIGN EDUCATION

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ABSTRACT

In Engineering Design education, huge numbers of students are a challenge in university teaching, especially since the students have an initially heterogeneous level of technical knowledge, which influences their acquisition of competences. In frontal classroom lectures, individual deficits can hardly be addressed and in self-study phases, students find it difficult to remedy these independently. Therefore, students with prior technical experience achieve better final module grades. This paper examines the extent to which heterogeneity in prior experience can be compensated by using an adaptive e-learning environment for the self-study time. For this purpose, students are provided with a prototypical implementation of an adaptive e-learning environment for the self-learning phase. The feedback of the users and their examination results are statistically evaluated with respect to the gain of knowledge.

KEYWORDS

Adaptive e-Learning, Engineering Design Education, Student-Centered Learning, Individual Learning Paths

1. INTRODUCTION

Higher education faces the challenge of increasing student heterogeneity (Eckert et al., 2015). Students of Engineering Design have different technical education at the beginning of their studies ("prior experience"): their secondary school education differs, and some students complete technical internships or technical training before their studies while others do not; i. e. it is a knowledge heterogenous student group. Differences in prior experience influence competence acquisition and the final module grade of students (Žeželj and Miler, 2018; Kannengiesser et al., 2015; Metraglia et al., 2015; Kossack and Bender 2022). Individual support decreases heterogeneity (Brückner *et al*., 2015), but Design engineering education can hardly guarantee individual support in the existing teacher-centered lectures with large learning groups (Pfäffli, 2015; Eckert, 2015; Albers, 2012; Terkowsky, 2018). Adaptive e-learning is a means to provide individual support (Stoyanov and Kirschener, 2004; Rey, 2009; Kerr, 2016; Niegemann and Heidig, 2019), and we suggest it for Engineering Design education (Kossack *et al*. 2022).

The impact of adaptive e-learning on knowledge heterogenous student groups is unknown. Research on adaptive e-learning addresses software solutions for adaptive e-learning (Fidalgo-Blanco, 2014), or collecting and using data for adaptivity (e.g., Bagheri, 2015; Radenkovic *et al.*, 2009), and adaptivity often in the context of different learning styles (e.g., Kolekar, 2019). Few authors evaluate the general benefit of adaptive e-learning for reaching learning outcomes (e.g., Prusty and Russell, 2011), even less with the focus on prior experience (e.g., Arsovic and Stefanovic, 2020), and we did not find any example for adaptive e-learning's impact on knowledge heterogenous student groups.

The purpose of this paper is to investigate the extent to which adaptive e-learning can compensate technical knowledge heterogeneity in a first-year student group of Engineering Design. We use an adaptive e-learning environment prototype (AdE-Le, see Kossack and Bender 2023) as a lecture-accompanying support for the self-study time and investigate the benefits of AdE-Le by comparing students with and without prior technical education in their behavior, their feedback on AdE-Le, and their exam results after using AdE-Le. Due to the

characteristics of an adaptive e-learning environment and the knowledge heterogeneity with the resulting consequences at hand, the following research hypotheses are formulated:

- H1: "Students without prior technical experience find AdE-Le more helpful than students with prior technical experience."
- H2: "An adaptive e-learning environment compensates initial technical knowledge heterogeneity to the point there exist no difference in the examination results between the groups."

2. METHOD

The investigation is conducted on a first-year course in Engineering Design education with about 150 regularly attending participants. It is part of the study programs of "mechanical engineering" and "sales engineering and product management" at a German university. The dominant learning format is teacher-centered lectures on campus, with consulting hours and self-study time as additional teaching and learning activities.

We use our prototype of an adaptive e-learning environment (AdE-Le, see Kossack and Bender 2023), which we implemented in the learning management system Moodle (Moodle Contributors, 2023) for the teaching and learning content "dimensioning, tolerancing and fitting tolerances". AdE-Le addresses individual needs and preferences of the user. It presents an initial learning environment to the user based on an assessment. During use, it makes further measurements of the level of knowledge or learning characteristics to bring about a constant modification of the learning environment; this is conformed with definitions of Stoyanov and Kirschener (2004), Rey (2009), and Kerr (2016). AdE-Le is developed in accordance with Constructive Alignment for an existing course (Kossack *et al*., 2022); Constructive Alignment is an outcome-based approach assigning Teaching and Learning Activities and the Assessment Task to Intended Learning Outcomes (Biggs and Tang, 2011).

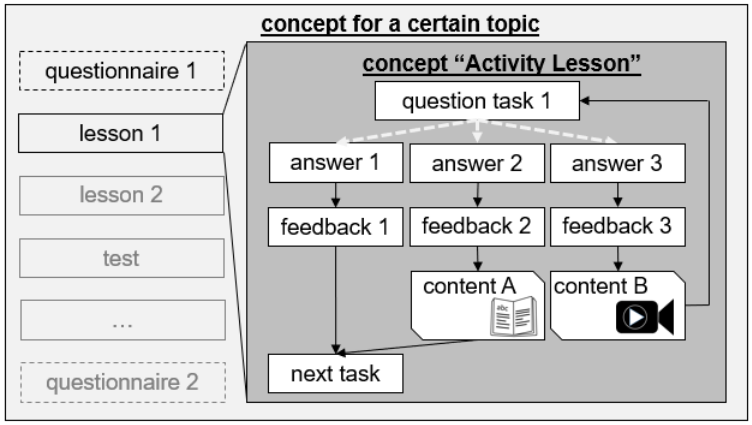

Figure 1. Concept of the implementation of AdE-Le in Moodle (see Kossack and Bender, 2023)

AdE-Le's main environment is based on the Moodle functions "Activity Lesson" and "Activity Test", with four lessons and two tests in total. For evaluation, we integrated two questionnaires with the Moodle function "Activity Survey" which conform to standard characteristics of questionnaires including variables with their scale levels according to Rasch (2021) and Döring and Bortz (2016). We use typical gradations for each variable: frequency from always (1) to never (5), or agreement from strongly agree (1) to strongly disagree (5). The AdE-Le uses the Moodle function Activity Lesson to combine content pages with pages for branching or with questions. When the student chooses an answer, the AdE-Le gives feedback and usually recommends assigned learning content. The learning contents are integrated as directly as possible: e.g., videos or interactive content in H5P (H5P Contributors 2023) format are embedded; book chapters or norms are recommended but not integrated in the system. (Kossack and Bender 2023).

To encourage students to use AdE-Le and give feedback, additional points were added to the exam grade for completing all activities of AdE-Le. Points were awarded for participation including submission of the feedback questionnaire; there was no gradation for the time, or the number of attempts students needed to

complete a learning unit. AdE-Le was available to all participants of the Moodle course belonging to the Engineering Desing course. Only datasets of students in the first semester are considered in the data, as students repeating the subject for a better grade could distort the results with the experience they gained in higher semesters. To introduce AdE-Le to the students, we used a teacher-centered lecture when the topic "dimensioning, tolerancing and fitting tolerances" started about 8 weeks after semester start. We presented the students how to use AdE-Le and how to get extra points for the exam. We informed the students that AdE-Le is a prototype for first time use, encouraged them to report errors or problems and informed them about the research with the data we collect with AdE-Le. Immediately after the lecture we unlocked the first activity in AdE-Le.

The first activity in AdE-Le is a questionnaire which we use to determine whether the students have different technical backgrounds and whether this leads to differences in competence. One example item of the questionnaire is the perceived degree of difficulty of the course. Findings from the questionnaire help to assess the extent to which the group is an appropriate sample for this study; it did not have an influence on the lessons in AdE-Le. By completing the first questionnaire, students unlocked the first lesson. Five subsequent learning activities were unlocked in coincidence with the content in the teacher-centered lectures and the six learning activities were linked together via prerequisites: Students could not start a new activity until the previous one was completed. We planned the use of one learning activity per week and offered technical support in existing consulting hours if needed. The second questionnaire unlocked after completing the last learning activity. It asks students on their behavior and the extent to which they assess AdE-Le as helpful for the self-learning phase. Table 2 presents the relevant items for this research. The results are stored anonymously for honest feedback. We asked students to specify their prior technical experience after they had completed all activities and registered for the extra points but did not require them to provide any information and there was no disadvantage if they refused to provide information. Their information on the prior technical experience is crucial for analyzing its correlation with student results in the final exam tasks.

Students could access the learning activities almost until the final written exam date which was a few weeks after the lecture period. Exam tasks included tasks that AdE-Le addressed as well as tasks with learning objectives that address other contents of the course, e.g., spatial sense or different views of a component.

For statistic evaluation, we divide the data sets into two groups without considering the specification of the type of prior technical education. The groups are (1) with prior technical experience and (2) without prior technical experience. We formulate the operational hypotheses H1 in a pair of research hypotheses as suggested by Döring and Bortz (2016). The null hypothesis assumes that there is no real difference between the groups that differ in terms of a characteristic (Rasch 2021). The rejection range is defined by the significance level, which is usually set at 5% (Hollenberg, 2016; Moosbrugger and Kelava, 2012). We transform the operational hypotheses H1 "Students without prior technical experience find AdE-Le more helpful than students with prior technical experience." into the null hypothesis H10 "There is no difference between the two groups in evaluating AdE-Le as helpful for their self-study time." The operational hypotheses H2 "An adaptive e-learning environment compensates initial technical knowledge heterogeneity to the point there exist no difference in the examination results between the groups." transforms into the null hypothesis H20 "There is no difference between the two groups in the exam results after using AdE-Le". The tool for quantitative analysis was SPSS for Windows (28.0.1.1).

3. RESULTS

134 students from the first semester started using the e-learning environment AdE-Le and participated in the first questionnaire; 29 of 134 students have prior technical experience. 75 students completed all activities of AdE-Le and filled out the second questionnaire with feedback on AdE-Le; 17 of 75 had a prior technical experience, and 61 of 75 participated in the final exam and volunteered information about their prior technical experience. 70 % of the students with prior technical experience and 80% of the students without prior technical experience did not use AdE-Le weekly as we intended, but only after the end of the lecture for exam preparation. Table 1 presents the frequency of use of the content that AdE-Le suggested. Students with prior technical experience used the suggested content slightly more often with an average of 2,3 to an average of 2,59 for students without prior technical experience. Significance tests show that the difference of user behavior is not statistically significant.

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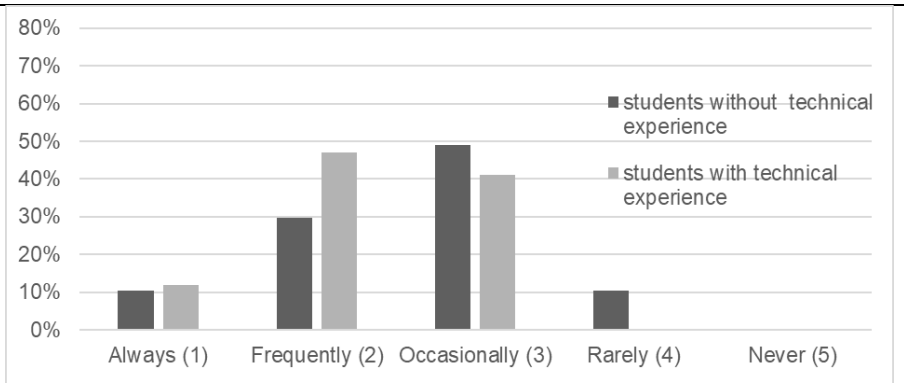
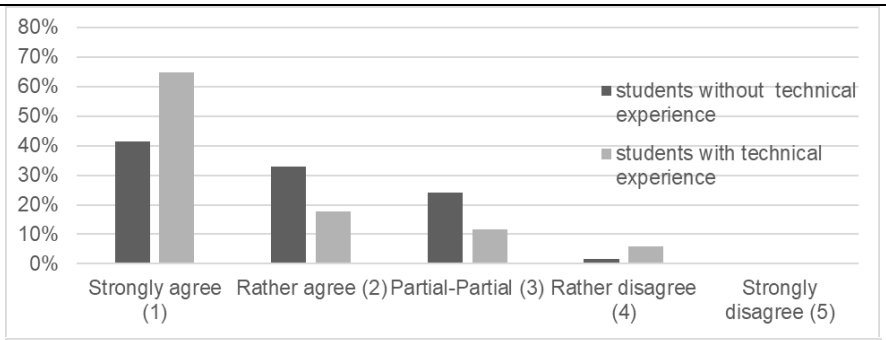
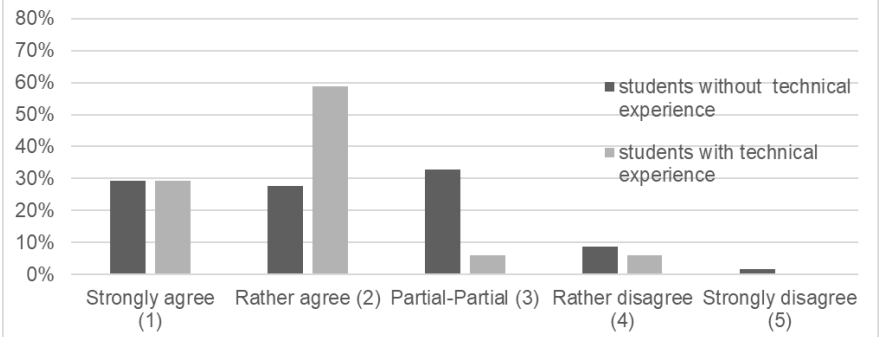
Table 1. Item of the user behavior from the second questionnaire. Note that group sizes differ

Item in the questionnaire	Results
Frequency: **"How often did you use the suggested content**? " Average students without prior technical experience 2,59 (n=58) Average students with prior technical experience 2,30 (n=17)	

The relevant items of the second questionnaire are assessed within this paper in Table 2. There were hardly any differences between the two test groups. The biggest difference in the average values can be seen in the agreement that AdE-Le supports the self-learning phases in a meaningful way. Here, the agreement of the group with prior technical experience is higher and can be described as weakly significant (p=0.042). For all other items the null hypothesis H10 is not rejected and there is no statistically significant difference between the two test groups.

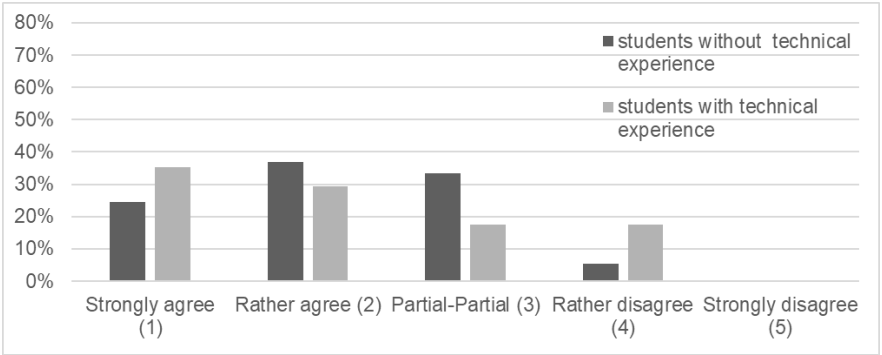
Table 2. Relevant items of Feedback about AdE-Le from the second questionnaire. Note that group sizes differ

Item in the questionnaire	Results
Agreement: **"I wish AdE-Le would be available for all topics in Engineering Design education."** Average students without prior technical experience 1,86 (n=58) Average students with prior technical experience 1,59 (n=17)	
Agreement: **"AdE-Le presented practice-oriented information."** Average students without prior technical experience 2,25 (n=58) Average students with prior technical experience 1,88 (n=17)	

"AdE-Le presented important technical background knowledge."

Average students without prior technical experience 2,19 (n=58)

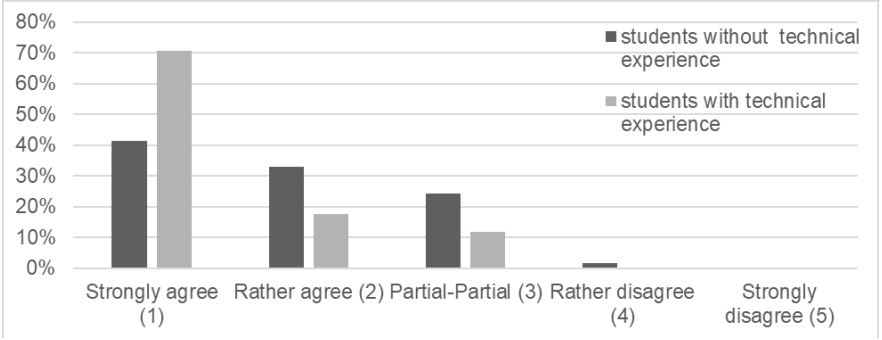
Average students with prior technical experience 2,17 (n=17)



Agreement:
"AdE-Le has meaningfully supported the self-study time."

Average students without prior technical experience 1,86 (n=58)

Average students with prior technical experience 1,41 (n=17)



In the exam students with a prior technical experience score higher on average in both tasks than students without prior technical experience (see Table 3). However, the difference is significantly greater for topics for which no AdE-Le was offered. When correlated with the group variable of whether prior technical experience is present, the significance is $p = 0.277$ for the task whose learning objectives are addressed by AdE-Le. Therefore, the operational null hypothesis that there is no difference between the two test groups using AdE-Le is accepted. For the task whose learning objectives are not addressed by AdE-Le, the significance is $p < 0.001$. Thus, for this task, the operational null hypothesis that there is no difference between the two groups is rejected. And the alternative hypothesis, that there is a different between the two groups is accepted. Initial differences between the two test groups could no longer be identified as significant in the written exam task whose learning objectives were addressed by AdE-Le.

Table 3. Final exam results of students who used AdE-Le

	Task with learning objectives addressed by AdE-Le	Task with learning objectives not addressed by AdE-Le
Students with prior technical experience (n = 17)	Average = 17,06points Standard deviation = 5,63	Average = 22,59 points Standard deviation = 2,97
Students without prior technical experience (n= 44)	Average = 15,59 points Standard deviation = 6,21	Average = 17,32 points Standard deviation = 6,61

4. DISCUSSION

Our first step is to ensure that the data is suitable to investigate our research hypotheses. Like in our previous study (Kossack and Bender, 2022), results of this study show that students with prior technical experience rate the level of difficulty of the course lower and rate their experience and knowledge as helpful for the acquisition of competences in the course. Based on the confirmed characteristics of the student group like Kossack and Bender (2022), the sample is suitable for investigating the research hypotheses.

It is crucial for comparing the two test groups that they used AdE-Le in similar ways. Results show that there is no significant difference between the two test groups in their usage behavior with AdE-Le.

We could not find that students without prior technical experience find AdE-Le more helpful than students with prior technical experience (H1) based on the results of questionnaire two. Results show that students with prior technical experience tend to rate the learning environment as more helpful and the material as more suitable, but this may be due to a fundamentally higher interest in the topics and not exclusively to the type of learning format.

We found that an adaptive e-learning environment leads to a homogenization of the exam results (H2), but it is unclear whether the AdE-Le lead to the homogenization or homogenization is a result of comparing two exam tasks with different topics. Data from exams tasks with the same learning objectives in different years of students not using AdE-Le could provide more insights on its effect.

The award of extra points for the exam might have influenced user behavior and study results. By awarding extra points on the exam through participation, students were motivated to participate and provide feedback. Instead of using AdE-Le as intended, students may instead use AdE-Le to get the extra points. An efficient way to get the extra points is to complete the activities as quickly as possible and only used the content to a limited extent, which we observed for many students of both groups (see Table 1). As a result, students assess content in the second questionnaire that they have worked on occasionally.

All results highly depend on the implemented AdE-Le. The Moodle system stored a limited number of available learning content, consists of several individual learning paths, and is adaptive solely in terms of knowledge level. The branching to learning content is predominantly done by selecting answer options for closed question types. Due to the limited possibilities of automated checking of learning objectives, higher taxonomy levels according to Bloom could hardly be implemented (Mayer *et al*. 2009), even by using Stack in Moodle. Therefore, learning objectives could not always be sufficiently checked and the learning status recorded to provide suitable materials for the individual student. The expansion of testing opportunities and integrated learning materials and learning paths could lead to an increased homogenization of the group.

Study results are limited to the subject “dimensioning, tolerancing and fitting tolerances” in Engineering Design education. These topics are typical for a gap of knowledge between the two groups of students (1) without prior technical experience and (2) with prior technical experience e.g., technical internship or vocational training. The impact of the use of an adaptive e-learning environment could be less in other topics. The development, implementation, and evaluation of adaptive learning environments on other topics in Engineering Design education and in other disciplines would reveal the extent to which the effect shown in this study applies to other topics as well.

The proportion of first semester students with prior technical experience is significantly lower than in Kossack and Bender (2022). Especially the proportion of students with a technical internship planned for the degree program at 12 % is considerably lower than it was at Kossack and Bender (2022) at 37%. The result for this study is very different sizes of the test groups. But these does not distort results due to similar variances, therefore the results can be considered representative despite the lower percentage of students with technical experience than Kossack and Bender (2022). Overall, both test groups viewed the learning environment in a meaningful and positive way. This could be due to the selection of the test group. In principle, AdE-Le was available to all students of the course, but not all students used or completed it. We assume that the test groups consist of students with the same level of motivation and interest in the topic.

The grouping of students is based on whether or not students have already started or completed another technical degree program, technical vocational training, or technical internship relevant to that degree program. The assumption that the students have more technical experience relevant to the acquisition of competencies than, for example, students who are very interested in technology in their free time but did not start any technical training or education can be wrong. Perhaps a knowledge survey to group by actually existing technical knowledge could provide better clues for grouping in this case.

This paper could not address all questions of interest concerning the benefits of adaptive e-learning environments. The general added value of the AdE-Le could be addressed by comparing the exam results of AdE-Le users with those of students who do not use an adaptive e-learning environment. The correlation between the usage behavior and the evaluation of the added value of the e-learning environment is relevant. With the data we could correlate the items of the feedback questionnaire (usage behavior and assessment of the personal benefits). It is not possible to investigate a correlation between user behavior and exam results with this data set, because data collection of the feedback questionnaire was anonymous.

5. CONCLUSION

It is desirable to homogenize student groups with typically differing prior technical experience in Engineering Design education to support competence acquisition. Individual support addresses heterogeneity and adaptive e-learning environments enable individual support in Engineering Design education. Our study investigates the use of an adaptive e-learning environment to provide individual support with data from two questionnaires. The students in the first semester in Engineering Design consider the adaptive e-learning environment a useful support for the self-learning phase. Slightly more students with prior technical experience than students without prior technical experience state that the adaptive e-learning environment supports in a meaningful way, but the evaluation of the exam results shows that the learning environment especially helps the test group without prior technical knowledge. Significant correlations between exam results and prior technical experience do not exist for exam tasks with learning objectives addressed by the adaptive e-learning environment, but they exist for other tasks of the same exam. Based on these results, the exemplary used Moodle-based implementation AdE-Le seems reasonable for knowledge heterogeneous student groups. Comparing multiple student groups from different years could be useful. Our findings are based solely on the topic area of "dimensioning, tolerances, and fits", so an extension to other topics would be useful. Further data analysis should compare the group of students who did not use AdE-Le with the group of students who did use AdE-Le to examine the fundamental benefits.

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REFERENCES

Albers, A.; Denkena, B.; Matthiesen, S.: Faszination Konstruktion. Berufsbild und Tätigkeitsfeld im Wandel. 2012.

Arsovic, B. and Stefanovic, N. (2020), "E-learning based on the adaptive learning model: case study in Serbia", Sādhanā, Vol. 45 No. 1, p. 1927.

Bagheri, M. (2015), "Intelligent and Adaptive Tutoring Systems: How to Integrate Learners", International Journal of Education, Vol. 7 No. 2, p. 1.

Berger, S. and Moser, U. (2020), "Adaptives Lernen und Testen", *journal für lehrerInnenbildung* jlb 01-2020 Digitalisierung https://doi.org/ 10.35468/jlb-01-2020_03.

Biggs, J.B. and Tang, C.S.-k. (2011), Teaching for quality learning at university: What the student does, UK Higher Education OUP Humanities and Social Sciences Higher Education OUP Ser, 4th edition, McGraw-Hill/Open University Press, Maidenhead.

Brückner, S., Förster, M., Zlatkin-Troitschanskaia, O. and Walstad, W.B. (2015), "Effects of prior economic education, native language, and gender on economic knowledge of first-year students in higher education. A comparative study between Germany and the USA", Studies in Higher Education, Vol. 40 No. 3, pp. 437–453.

Döring, N.; Bortz, J.(2016); *Forschungsmethoden und Evaluation in den Sozial- und Humanwissenschaften*. Berlin, Heidelberg: Springer Berlin Heidelberg 2016

Eckert, C., Seifried, E. and Spinath, B. (2015), "Heterogenität in der Hochschule aus psychologischer Sicht: Die Rolle der studentischen Eingangsvoraussetzungen für adaptives Lehren", in Rheinländer, K. (Ed.), *Ungleichheitssensible Hochschullehre*, Vol. 11, Springer Fachmedien Wiesbaden, Wiesbaden, pp. 257–274 https://doi.org/ 10.1007/978-3-658-09477-5_14.

Fidalgo-Blanco, A., Sein-Echaluce Maria Luisa, Garcia-Penalvo, F.J. and Conde-Gonzalez, M.A. (2014), "Learning content management systems for the definition of adaptive learning environments", in 2014 International Symposium on Computers in Education (SIIE): 12 - 14 Nov. 2014, Logroño, La Rioja, Spain, IEEE, Piscataway, NJ, pp. 105–110.

H5P Contributors (2023), available at: https://h5p.org/.

Hollenberg, S (2016), *Fragebögen*. Wiesbaden: Springer Fachmedien Wiesbaden 2016.

Kannengiesser, U.; Gero, J.; Wells, J.; Lammi, M. (2015) DO HIGH SCHOOL STUDENTS BENEFIT FROM PRE-ENGINEERING DESIGN EDUCATION? *Proceedings of the 20th International Conference on Engineering Design (ICED15).* 2015.

Kerr, P. (2016), "Adaptive learning", *ELT Journal*, Vol. 70 No. 1, pp. 88–93 https://doi.org/ 10.1093/elt/ccv055.

Kolekar, S.V., Pai, R.M. and M. M., M.P. (2019), "Rule based adaptive user interface for adaptive E-learning system", *Education and Information Technologies*, Vol. 24 No. 1, pp. 613–641 https://doi.org/ 10.1007/s10639-018-9788-1.

Kossack, F. and Bender, B. (2022), "Heterogeneous groups of students as a challenge in engineering design education", in DS 119: *Proceedings of the 33rd Symposium Design for X (DFX2022)*, 22 and 23 September 2022, The Design Society, p. 10 https://doi.org/ 10.35199/dfx2022.07.

Kossack, F., Bender, B. (2023) 'Individualization in Engineering Design Education: Implementation of an Adaptive E-Learning Environment (AdE-Le)', *in Proceedings of the International Conference on Engineering Design* (ICED23), Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.230

Kossack, F., Kattwinkel, D. and Bender, B. (2022), "Adaptive E-Learning for the Engineering Design Education at Ruhr-University Bochum", Proceedings of the Design Society, Vol. 2, pp. 2313–2322 https://doi.org/ 10.1017/pds.2022.234.

Mayer, H.O. and Hertnagel, J. (2009), *Lernzielüberprüfung im eLearning*, Oldenbourg, München https://doi.org/ 10.1524/9783486848984.

Metraglia, R., Villa Valerio, Baronio Gabriele and Adamini, R. (2015), "High School Graphics Experience Influencing the Self-Efficacy of First-Year Engineering Students in an Introductory Engineering Graphics Course", *Engineering Design Graphics Journal (EDGJ)*, No. Vol. 79 No.3.

Moodle Contributors (2023), "Fragetyp STACK", available at: https://docs.moodle.org/400/de/Fragetyp_STACK

Moosbrugger, H. u. Kelava, A. (2012) *Testtheorie und Fragebogenkonstruktion*. Springer-Lehrbuch. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg.

Niegemann, H.M. and Heidig, S. (2019), "Interaktivität und Adaptivität in multimedialen Lernumgebungen", in Niegemann, H. and Weinberger, A. (Eds.), *Lernen mit Bildungstechnologien*, Springer Reference Psychologie, Vol. 73, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 1–25 https://doi.org/ 10.1007/978-3-662-54373-3_33-1.

Pfäffli, B. K. (2015): Lehren an Hochschulen. Eine Hochschuldidaktik für den Aufbau von Wissen und Kompetenzen. UTB Schlüsselkompetenzen Hochschuldidaktik, Bd. 4325. Bern: Haupt 2015.

Prusty, B. G., & Russell, C. (2011). Engaging students in learning threshold concepts in engineering mechanics: adaptive eLearning tutorials. In 17th International Conference on Engineering Education (ICEE) (pp. 21-26).

Radenkovic, B., Despotovic, M., Bogdanovic, Z. and Barac, D. (2009), "Creating Adaptive Environment for e-Learning Courses", JIOS, Vol. 33 No. 1, pp. 179–189.

Rasch, B. (2021), Quantitative Methoden. Einführung in die Statistik für Psychologie, Sozial- und Erziehungswissenschaften. Lehrbuch. Berlin: Springer.

Rey, G.D. (2009), *E-Learning: Theorien, Gestaltungsempfehlungen und Forschung*, Psychologie-Lehrbuch, 1. Auflage, Verlag Hans Huber, Bern.

Rusak, Z. (2017), "EXPLOITATION OF MICRO-LEARNING FOR GENERATING PERSONALIZED LEARNING PATHS", *in Proceedings of the 21th International Conference on Engineering Design (ICED17)* Vol. 9: Design Education 21.-25.08.2017, Vancouver, Canada.

Stoyanov, S. and Kirschener, P. (2004), "Expert Concept Mapping Method for Defining the Characteristics of Adaptive E-Learning: ALFANET Project Case", *ETR&D*, Vol. 52 No. 2, pp. 41–56.

Terkowsky, C., Frye, S., Haertel, T., May, D., Wilkemann, U. and Jahnke, I. (2018), "Technik- und Ingenieurdidaktik in der hochschulischen Bildung", in Pittich, D., Zinn, B. and Tenberg, R. (Eds.), *Technikdidaktik: Eine Bestandsaufnahme*, Franz Steiner Verlag, pp. 87–97.

Wissenschaftliche Gesellschaft für Produktentwicklung WiGeP e.V. (2018), Universitäre Lehre in der Produktentwicklung: Leitfaden der Wissenschaftlichen Gesellschaft für Produktentwicklung (WiGeP). Available at: https://b7s1f6.n3cdn1.secureserver.net/wp-content/uploads/2022/05/Final_WiGeP_Leitfaden_Lehre.pdf

Žeželj, D. and Miler, D. (2018), MANUFACTURING TECHNOLOGY-BASED APPROACH TO TEACHING ENGINEERING DRAWING. *Proceedings of the DESIGN 2018* 15th. Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia; The Design Society, Glasgow, UK 2018, S. 2553–2562