



## INTEGRATED CONCEPT FOR THE ENHANCEMENT OF MATHEMATICAL COMPETENCIES AT THE TRANSITION FROM HIGH SCHOOL STUDENT TO FRESHMEN IN ENGINEERING STUDIES

### **A Nasarow**

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany,  
Department of Mechanical Engineering  
Erlangen, Germany  
ORCID 0000-0003-2068-9645

### **P Schmitt**

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany,  
Department of Mechanical Engineering  
Erlangen, Germany  
ORCID 0000-0002-0946-6216

### **O Kreis**

Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany,  
Department of Mechanical Engineering  
Erlangen, Germany  
ORCID 0000-0002-6207-7260

**Conference Key Areas:** *Mathematics at the heart of Engineering, Attractiveness of Engineering*

**Keywords:** *mathematic education, high school, freshmen, study entrance level*

### **ABSTRACT**

This concept paper presents the large-scale measures and results that the Faculty of Engineering of the Friedrich-Alexander Universität Erlangen-Nürnberg (FAU) has developed to shape the future of learning and teaching of propaedeutic skills in the field of mathematics as a central basis of engineering subjects and to inspire pupils and young people for engineering studies. Since 2020, the Faculty of Engineering has developed a three-tier, structured voluntary program that is attended by several thousand pupils and freshmen per year:

1. Summer review courses in mathematics for pupils after the 10th and 11th school year during the summer holidays in accordance with the Bavarian school curriculum

2. School leaving exam preparation courses in mathematics shortly before the university-entrance diploma acquired at a secondary school in Germany, the so-called "Abitur"

3. Math review courses for freshmen.

The methodological approach of the article lies in the presentation of the educational measures and in the analysis of the results of systematic student evaluations. This leads to generalizable, transferable recommendations for the future design of such large-scale measures for universities, derived from answering the proposed research questions and evaluation results.

## **1 INTRODUCTION: MATH ANXIETY - DIFFICULTIES FOR A SUCCESSFUL HIGH SCHOOL EXAM AND STUDY ENTRY IN ENGINEERING AND NATURAL SCIENCES**

For years, the math skills of prospective high school graduates in Germany have been very "different" (many good, many just sufficient) with a large spread. There is a variety of literature available as mathematical support for pupils, such as "Taking Fear Out of Math: A Self-Help Guide for Parents and Students" [1] or – in German language – "Keine Angst vor Mathe" [2] or "Mathe ohne Angst" [3], and also scientific literature for teachers to overcome the "fear of mathematics" of their pupils and students such as "Math Anxiety: Strategies to Increase Confidence in Your Students Who Fear Math" [4], "I'm Just Not A Math Person! - Recognizing, Understanding, and Managing the Fear of Mathematics" [5] or "Mathematik-bezogene Angst" (in German language) [6]. On the other hand, the authors of this paper are not aware of any comparable books for other school subjects such as "Don't be afraid of English" or "History without fear". Due to the CoViD-19 pandemic, there are further gaps in skills due to the absence of contact teaching and initial difficulties with homeschooling during the lockdown phases, especially in 2020. All these topics discourage many high school graduates from taking up engineering and natural science study programs.

## **2 DESCRIPTION AND METHODOLOGY**

### **2.1 Description and overview**

For years, FAU has been offering its "Mathematics Review Course for Freshmen" ("Mathematik-Repetitorium") before the start of the winter semester. The mathematics topics from high school are repeated in the two weeks before the start of the lecture period. In this way, the heterogeneous degrees of knowledge of the first semester students can be evened out.

The integrated concept presented in this paper describes an approach that starts much earlier in the "student life cycle". For this purpose, the review course for freshmen was enhanced to a structured offer in three graded and coordinated courses offered online via Zoom (see Fig. 1):

1. Summer review courses in mathematics for pupils after the 10th and 11th school year during the summer holidays in accordance with the Bavarian school curriculum (tutorials in groups of around 15 participants each, duration 6 weeks during the summer holidays with 2 hours of tutorials per week). The educational ideas and objectives are to close gaps in education incurred in the previous 10th and 11th school year and to prepare the pupils for the coming school year.
2. School leaving exam preparation courses in mathematics in April shortly before the German high school leaving exams, the “Abitur” in May complemented by information events on the range of degree programs offered at FAU (tutorials in groups of approx. 15 participants each, duration 2 weeks during the Easter holidays with 3 hours of tutorials daily). The educational objectives are to transfer competencies to enable the pupils to pass the high school leaving exams in maths with good grades, especially for pupils that are not confident in their mathematics abilities, to attract them to engineering studies and – ideally – to FAU.
3. Math review courses for freshmen of FAU (lectures plus tutorials in groups of around 15 participants in the 2 weeks before the start of the regular lectures of the winter semester with daily 2 hours of lectures + 2 hours of tutorials; usually in attendance, in fall 2020 and 2021 online due to CoViD-19). The educational objectives are to refresh mathematical high school competencies for all students, especially for students that have passed their high school exam some years earlier due to a vocational education or a voluntary state service after the high school exam, and to prepare them for higher mathematics and mathematics oriented engineering courses in the first semesters.

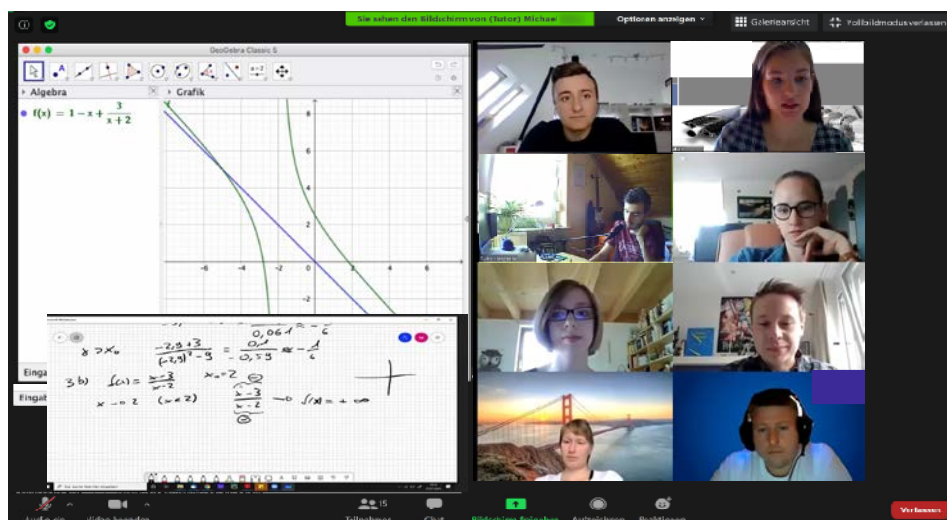


Fig. 1. Online tutorial mathematics

## 2.2 Key facts of the courses

Approximately 500 – 1 500 pupils registered for each course, which required the hiring of approximately 50 - 100 students per semester as tutors. The tutorials were mainly carried out by engineering students in order to ensure a high level of practical

relevance. These were supplemented by students from the natural sciences faculty, mainly by students from the mathematics teacher training program. The costs for tutors also formed the largest part of the required material resources (approx. 25 000 – 50 000 € per course). The organization and scientific management was carried out by full-time staff from the Faculty of Engineering, here primarily from the Department of Mechanical Engineering.

Online research revealed that comparable courses are often offered at other universities for first semester students, but hardly any courses for pupils or courses to prepare for the high school leaving exam.

### **2.3 Pedagogical design: Engaging pupils' attention and motivating the pupils in the courses**

Since the summer courses were announced as "first aid maths course" for 10th and 11th grade pupils and "math Abitur crash courses", mostly pupils with deficits in mathematics participated (in contrary to "tech summer courses for pupils", where mostly math and engineering interested pupils participate). Therefore, the pedagogical design aimed to help these pupils to close their competency gaps by active work and to lower their maths anxiety: "math can only be understood by self working on exercises, not by listening to a lecture or watching tutors solving mathematical problems". No "classical lectures" ("Vorlesungen") with mostly passive students were offered and also no "blackboard exercises", where a tutor writes solutions of math exercises on the board and the students write them down in their notebook, but only tutorials (see Fig. 1).

In online courses, it is often hard to motivate students to do active work. To engage the pupils' attention, the Zoom sessions were created in a very interactive manner: students were asked to edit exercises on their own, they were (repeatedly) asked to turn on their cameras and often they were distributed to breakout rooms with about 3 students each for about 10 minutes to edit and discuss exercises while the tutors "jump" between the breakout rooms and answer questions.

For the courses in the 10th and 11th grades, the Faculty of Engineering did not develop own exercises, but exercise books from the school book series "Lambacher Schweizer" [7], used by most high schools in Bavaria, were used, and for the Abitur courses, the collections of Stark publishing house of the official exams of the Bavarian State Ministry of Education of the last years were used [8]. This ensured that the taught topics fit well to the school teaching plan and Abitur exams.

The following list shows exemplarily the topics of the 11th grade summer course [7]:

- Graphs of proper rational functions
- Differential calculus of real-valued single variable functions
- Applications of the derivative
- Analytic geometry
- Advanced techniques of differentiation



- Natural exponential and logarithm functions
- Probability and stochastic independence
- Applications of differential calculus

In the Abitur courses, each day the complete Abitur maths-exam of one of the last years were worked, covering the topics analysis, stochastic and geometry.

## 2.4 Research questions and evaluation methodology

The following research questions were defined and were answered by analyzing student evaluations:

1. What is a good course design for universities to improve mathematical skills in the last high school years and for high school leaving exams "Abitur" regarding practical and organizational considerations?
2. Which pupils choose voluntary maths review and Abitur courses regarding their mathematical competencies (mostly good pupils who want to become very good – or mostly "bad pupils" in math who want to become average)?
3. Additional question: How can you attract prospective high school graduates for engineering degree programs and for your university?

To answer these questions, mid-term and final evaluations were conducted in all courses. The results of the summer courses lead to recommendations for action for the school leaving exam preparation courses and these led to recommendations for the freshmen review courses.

In the case of only a final evaluation, the course members are only moderately motivated to take part, since there can be no further improvement in the current course (response rates about 10 to 30%). In order to be able to implement improvement measures in the second half of the course, an additional mid-term evaluation was carried out halfway through each course as an anonymous survey on the e-learning platform StudOn (Ilias) with response rates of about 50%, what is very good for an online evaluation. As a 3rd evaluation stage, a short survey was carried out for the school leaving exam preparation courses about one month after the last high school exams took place to analyze retrospectively if these course were helpful to pass the maths exam.

## 3 STUDENT LEARNING GAINS

### 3.1 Evaluation outcomes and effectiveness of the program

The evaluation shows that the summer review courses after the 10th and 11th school year during the summer holidays had a clearly positive effect on the image of the university (Fig 2). Most of the pupils (approx. 80%) rated the courses "very good" or "good", the degree of difficulty was mostly rated "just right". Many participants also showed interest in studying at FAU (across all disciplines). A large number of pupils

also would like to take part in a high school leaving exam preparation course based on this summer course. Due to these convincing evaluation results, the FAU offered this "Abitur" course for the first time in the Easter holidays 2021 and again in April 2022.

Here is a selection of typical quotes (translated from German) from the evaluation of the summer courses 2020 and 2021 [9]:

- "We think your offer is great, because maths teaching was almost completely absent for weeks - but everybody needs it as a compulsory subject in the 'Abitur'."
- "You never had the feeling of looking stupid, even if you had to ask more questions about an exercise before you understood it. I also thought it was pretty cool that we could always help each other and give tips."
- "The idea of a maths [...] course was a really nice idea and I fully support it if this course would be offered again in the years to come."
- "I recommend the course to everyone and if preparatory courses are offered in the spring before the 'Abitur', I would definitely take part again and I would be very grateful to FAU :D"

Points for improvement were, among other things, the differing quality of the tutorial teaching, too many exercises dealt within a too short amount of time and the long duration of the tutorials.

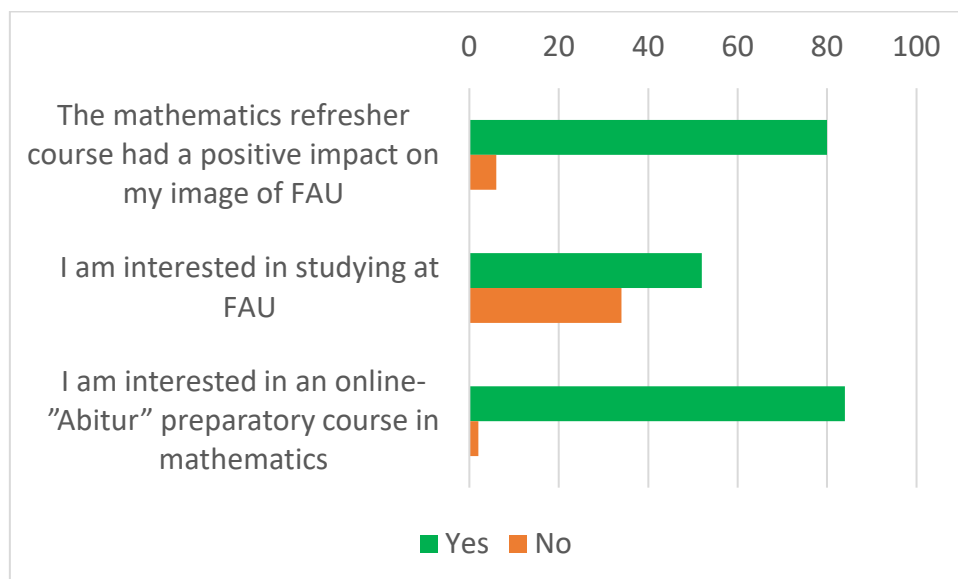


Fig. 2. Evaluation of the summer review course for 10<sup>th</sup> and 11<sup>th</sup> grades 2020

The final evaluation of the Abitur courses 2021 corresponds with the evaluation results from 2020 and was also very positive (Fig. 3). 85% of respondents rated the course as "very good" or "good" (n=582) and helpful, but they were still skeptical about their future success in their oncoming math high school leaving exams – only half of the respondents felt "very well prepared" or "well prepared" for their exams.

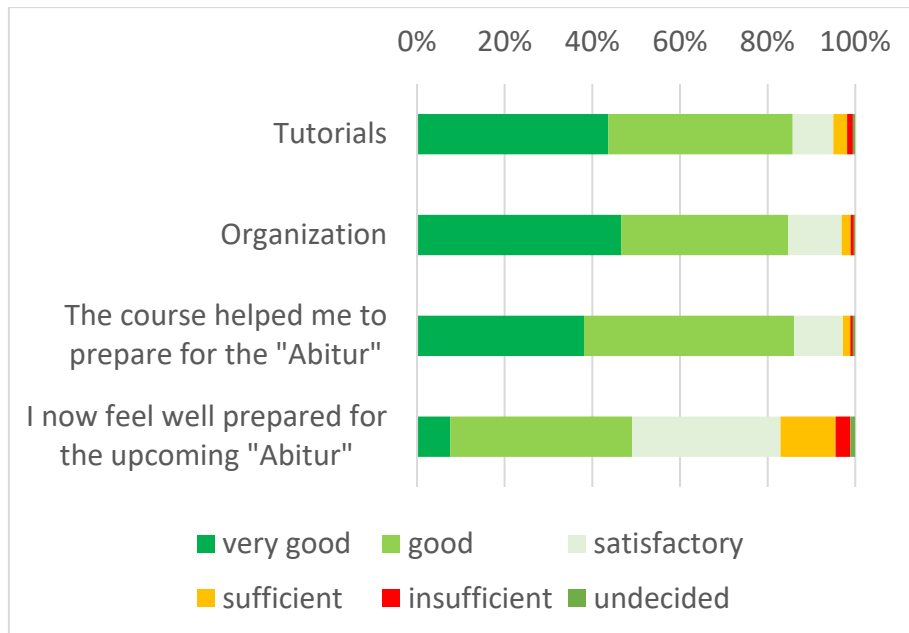


Fig. 3. Mid-term Evaluation of the Abitur course 2021, n=582

Due to the nationwide offer, many participants in the school leaving exam preparation course do not want to study at FAU, but rather at another university. Around 40% of high school graduates in the 2021 course did not yet know if they would like to study at FAU (see Fig. 4), which shows that there is great potential for the acquisition of future students at FAU. The evaluation also shows that fewer students who already have a strong affinity for technology and maths have taken the course, but rather those who have a lot of catching up to do in mathematics and who are a bit afraid of studying engineering. Only 15% were eager to study engineering (in 2022 this percentage was higher with 23%). Therefore, there is a great potential to attract future students for technical subjects who would otherwise hardly have sought out studying engineering.

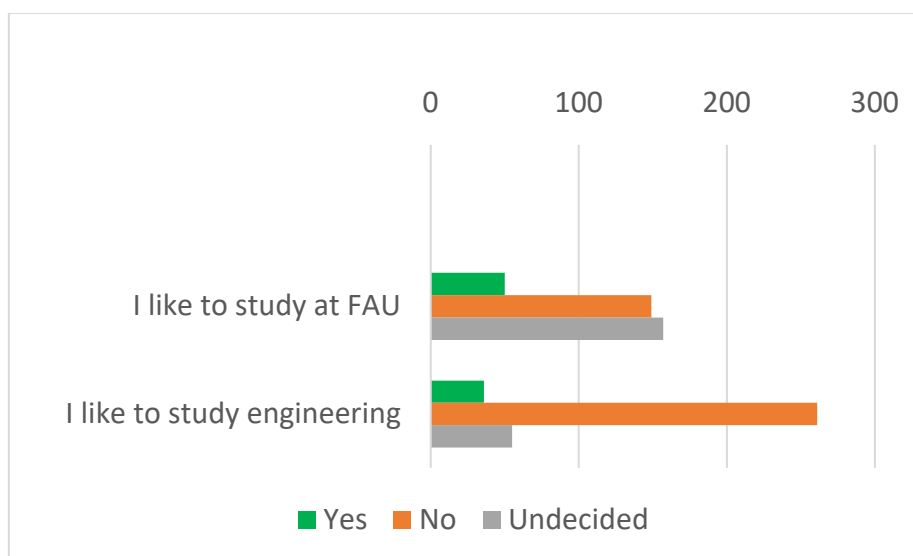


Fig. 4. Final evaluation of the Abitur course 2021



### 3.2 Answering the research questions

By analyzing the various evaluations, the following answers to the asked research questions were elaborated:

1. What is a good course design for universities to improve mathematical skills in the last high school years and for high school leaving exams "Abitur" regarding practical and organizational considerations?

- It's too late to start maths review with freshmen – you should start much earlier - one or two years before the high school leaving exams.
- Online courses (during school holidays) offered by universities are a great measure to improve mathematical skills. They transcend geographical borders and can make your own university/college known state-wide and even nation-wide.
- Offering tutorials with pupils working on their own is better than offering "classical lectures" or blackboard exercises, since "math anxiety can only be lowered by calculating math exercises". The last survey of the pupils cohort after the completion of the "Abitur" exams in July 2021 via the platform strawpoll.de was particularly revealing and confirmed the effectiveness of the courses (Fig. 5):

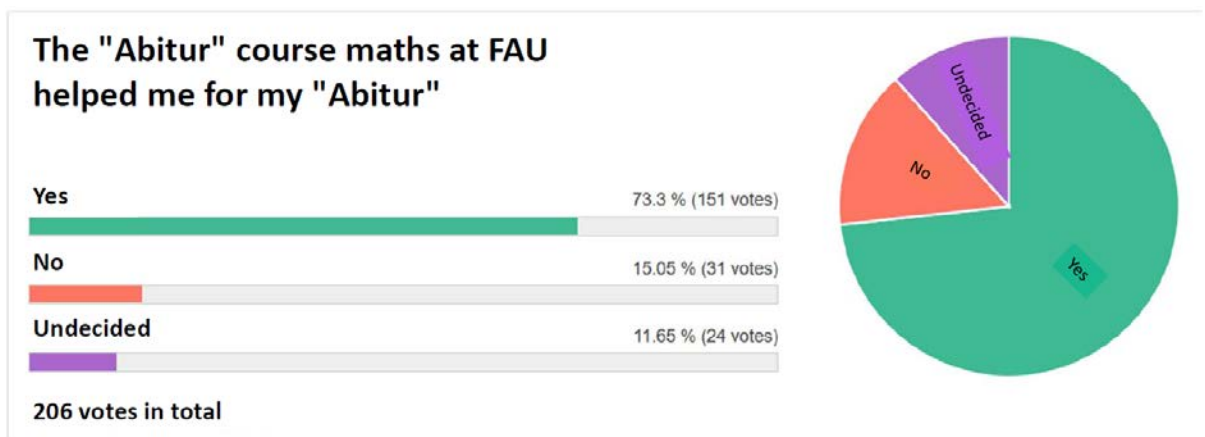


Fig. 5. "Post-evaluation" of the Abitur course 2021

#### Lessons learned - Recommendations for action

- Timely planning and information for schools (e.g. via e-mail to school mailing lists, parents' councils or publications [10])
- Provision of an efficient online registration system that pupils without a university account can use
- Timely licensing of the required teaching materials, publishers often offer cost effective bundled licences for teachers (so-called "Fachschaftslizenzen")





- Quality assurance of the tutors' teaching performance (partly criticism from the evaluation): conduct kick-off meeting with all tutors, implement tutor training with professional advisors (this was established from autumn 2021 on at FAU for all new tutors)
  - Planning of sufficient administrative capacities for the student tutors
  - Acquisition of financial resources if the courses are to be offered free of charge, or use of funding opportunities (e.g. federal programs like action programs to "catch up" after the Covid-19 pandemic)
  - Pre-planning of evaluations, propagate feedback of the mid-term evaluation to the tutors
2. Which pupils choose voluntary maths review and Abitur courses regarding their mathematical competencies (mostly good pupils who want to become very good – or mostly "bad pupils" in math who want to become average?)
- As expected, the courses attracted mostly high school pupils and graduates which were less interested in mathematics and therefore had great difficulties in maths. Therefore, the course design focussed on tutorials to encourage the pupils to do math exercises on their own.
3. Additional question: How can you attract prospective high school graduates for engineering degree programs and for your university?
- The course had a very positive impact on the image of FAU and especially its Faculty of Engineering.
  - Approximately 30-40% of high school graduates do not yet know whether or where to study. This shows great potential to attract these students for engineering study programs. Attractive accompanying study information events that are integrated in the maths review courses give the opportunity to strongly raise this percentage: "No fear of math" may lead to "engineering is cool".
  - Unfortunately, in the final evaluation of the Abitur courses, only 15% to 23% said that they want to study engineering. This shows that the "math anxiety" or disinterest in math and engineering could not be completely removed by these math courses, so further efforts must be made to inspire more students for engineering.

#### 4 SUMMARY AND ACKNOWLEDGMENTS

Consecutive maths review courses offered by universities on different levels starting from 10th/11th graded over high school leaving exam courses up to freshmen courses strongly help pupils to overcome problems in maths and enable pupils and students to loose their fear of maths and to attract them for engineering degree programs. They can strongly improve the image of the offering university. Online



courses transcend geographical borders and can make your own university/college known state-wide and nation-wide. The research questions of this concept paper will be further analysed and answered by ongoing examinations and evaluations of future courses.

Acknowledgements go to the Central University Administration of FAU and the Faculty of Engineering for financial support of the courses and especially to the many highly motivated student tutors and staff.

## REFERENCES

- [1] Seigler, W (2021), Taking Fear Out of Math: A Self-Help Guide for Parents and Students, independently published.
- [2] Poguntke, W (2010), Keine Angst vor Mathe, Vieweg+Teubner, Wiesbaden.
- [3] Burkhardt, G (2021), Mathe ohne Angst, mvg Verlag, Munich.
- [4] Bernard, B (2016), Math Anxiety: Strategies to Increase Confidence in Your Students Who Fear Math, CreateSpace Independent Publishing Platform.
- [5] Peters, B (2018), I'm Just Not A Math Person! - Recognizing, Understanding, and Managing the Fear of Mathematics, HenschelHAUS Publishing, Milwaukee.
- [6] Beier, F (2021), Mathematik-bezogene Angst, Springer Spektrum, Berlin.
- [7] Lambacher Schweizer: Mathematik für Gymnasien, Basistraining 11, Ausgabe Bayern (2020), Ernst Klett, Stuttgart/Leipzig.
- [8] Abitur Mathematik – Original-Prüfungsaufgaben mit Lösungen, Gymnasium Bayern (2021), Stark, München.
- [9] Kreis, O., Nasarow, A. (2022), Digitale Lehrangebote Mathematik in der Schul- und Studieneingangsphase ingenieurwissenschaftlicher Studiengänge, Proceedings of the 15th annual conference on engineering education 2021, Kammasch, G., Keil, S., Winkler, D. (Editors), Ingenieurpädagogische Wissenschaftsgesellschaft IPW e. V., Berlin, pp. 167-172.
- [10] Kreis, O., Schmitt, P., Nasarow, A. (2021): Mit der Universität Erlangen-Nürnberg zum erfolgreichen Mathe-Abitur, in: Association of German Engineers VDI, Technik in Bayern 2021, Vol. 2, p. 45.