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An innovative, technology-enhanced instructional approach to address the diverse competencies of STEM students in math classes

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Abstract

The transition from secondary to higher education in mathematics raises several challenges for students of STEM (Science, Technology, Engineering, Mathematics) studies. These include amongst others different emphases and requirements and the prohibition of computer algebra systems in basic math education at universities, which leads to a high dropout rate in the first year of study. To address these challenges, a so-called three-level system was introduced at TU Wien (Vienna University of Technology) in first-year mathematics courses to support and encourage students with different levels of high school knowledge. This approach entails several requirements such as a higher correction effort which is countered by the use of an e-learning system called Möbius. It not only provides automatic grading of exercises but also individual and immediate feedback for the students. The analysis of the grade distribution of two years indicates a positive influence of the introduced three-level system on first-year STEM students.

Keywords: *Innovative teaching; evaluation and assessment; e-learning strategies; new teaching models; STEM education; blended learning; technology enhanced teaching.*

1. Introduction

During the transition from secondary to university mathematics education, students experience various difficulties, which makes teaching methods at university an emerging research field, see Voskoglou (2019) and Körner et al. (2014). According to Pinto & Koichu (2022), there are several approaches in order to help students to overcome those challenges. All of which address different origins, including the discontinuitiy of mathematics education from secondary to university level. This describes the ability to perform algorithms to solve problems taught in secondary mathematics educations in contrast to deeper mathematical understanding required in university math courses of STEM studies.

In line with the results of Rylands & Coady (2009), students' mathematical competences and their ability to pass first-year STEM courses depend strongly on their mathematical background, i.e. the type of school attended and the quality of mathematics teaching. This results in a diverse group of students, some of whom do not have basic knowledge of calculus and cannot follow the constructive material, while others feel underchallenged if the level of mathematics taught is lowered.

Furthermore, the intensive use of computer algebra systems (CAS) in secondary mathematics education has a negative impact on students' understanding of how to manually do math and what it should look like, as pointed out in a Danish study by Jankvist & Misfeldt (2021). As the use of CAS is not allowed in university STEM courses of bachelor level, these deficits in general mathematical skills and understanding are reflected in students' results, not only in pure mathematics courses.

These challenges students are facing lead to a high dropout rate among first-year students in STEM studies, see Geisler, Rolka & Rach (2023), and therefore need to be addressed. The following section presents a general concept of the so-called three-level system that addresses these challenges in mathematics education. In addition, its application in various mathematical subjects at the beginning of the Bachelor's programme is briefly presented, including the use of an e-learning system called Möbius, formerly Maple T.A., which is explained in more detail in Winkler, Körner & Urbonaite (2012).

2. A three-level system to address different mathematical competencies

2.1. Structure of the three-level system

In order to meet the needs in third level mathematics education of a heterogenous group with different backgrounds and skills, a three-level system is designed. The system is established in the context of constructive alignment (objectives, assessment, education and teaching activities), explained further in Biggs (1996) and Wang et al. (2013). The proposed approach states what set of skills is expected from students as a learning outcome of the course (objectives). The three-level system focuses on providing feedback on students' current knowledge and skills so that they can continuously adapt their learning (assessment), whether they start with a low level of knowledge or already have more developed skills. Figure 1 illustrates the basic idea of the three learning levels of the proposed system (education and teaching activities).

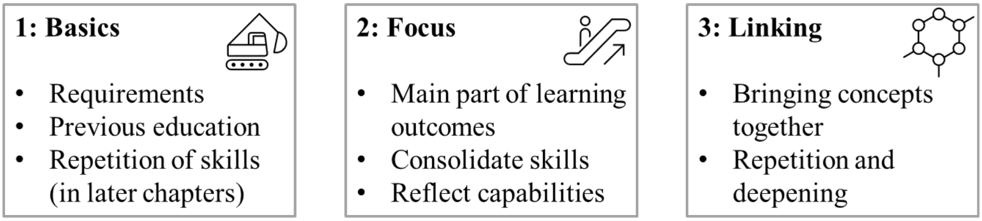

Figure 1. Overview of the key aspects of the three-level system.

The basic level (Level 1), clarifies the basic requirements for each chapter of the course so that students can enter with the necessary mathematical tools, also outlined in Dlouhá, D., Pospíšil & Dlouhá, K. (2022). This level is essentially based on secondary school mathematics and therefore focusses on algorithmic math knowledge, but is adapted to the topics of the respective course as it progresses. In this context, a set of exercises is provided at the beginning of a chapter and has to be solved within a deadline of one to two weeks. The completion is mandatory, but does not influence the final grade. Furthermore, students have an infinite number of attempts to complete this assignment. An example of this level presenting important concepts that the students should be familiar with in order to follow a course on real functions is illustrated in Figure 2.

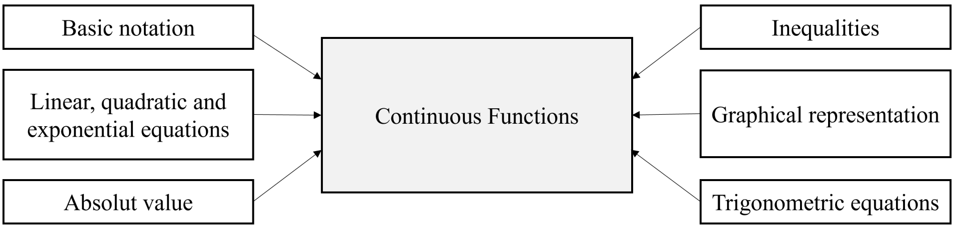

Figure 2. Basic concepts necessary for the topic of real functions.

The focus level (Level 2), addresses the learning outcomes to be achieved in the course. These are mostly the examples that were offered in the traditional form of the course solely. This level focusses on the application of results thought in level 1 to answer further advanced problems. For example, the basic knowledge about an exponential function is used to find range in which such a function must be bijective.The examples to be worked on in the framework of this level are discussed weekly in exercise groups where, depending on the respective course, the exercises will be either presented by a tutor or the students themselves. A certain percentage, e.g. at least 50%, of exercises has to be solved by the end of the course.

The linking level (Level 3), facilitates the linking of knowledge and skills of the different chapters. This level is oriented towards the final exam of the lecture, where the chapters are not asked piece by piece, but an example on two or more aspects is covered. Students who have not been exposed to this kind of examples usually have difficulties in the final exam, even if they can easily solve tasks on a single topic. In addition, the deepening of knowledge is promoted. To practise combining different topics independently, a typical example would ask students to give a function that satisfies the properties known from level 2, such as bijectivity and continuity. Of course, linking is less present at the beginning than in the later chapters of the course. Generally, exercises of this level are not mandatory, but give bonus points based on the quality of discussion of the student's solution with a tutor.

2.2. Application Scenarios

As of today, the three-level system was applied to two math courses for first-year students at TU Wien. It was first developed for the course Mathematics 1 for Electrical Engineering, Technical Physics, Geodesy and Geoinformation, and later on also applied to Practical Mathematics 1 for Technical Physics.

Mathematics 1 consists of a lecture and an exercise course, which are graded separately. The grade of the exercise course is composed of the percentage of second level examples solved, the quality of presentations, the sum of points of the three exams during the semester and possibly bonus points. The grade for the lecture course is based on the points achieved in the final exam that takes place at the end of the semester.

The three-level system was originally established for the course Mathematics 1, which consists of a lecture and an exercise. Therefore, it is directly applicable to this course in all aspects described and was later adapted to Practical Mathematics 1 while maintaining the basic idea.

3. Implications of the three-level-system

3.1. Emerging challenges

The following are the main challenges selected based on student feedback and lecturer experience. An obvious challenge is the increased workload for students and teachers in a course implementing the three-level system. Compared to traditional educational systems in this type of first-year mathematics course that implemented only the secondary level, those involved face an increased catalogue of demands during the semester. Several teachers and students complain about such systems - students about the increased workload, teachers about the increased supervision and correction effort. This system is only accepted if it tends to have a positive effect on students during the semester (preparation of midterm tests, weekly homework, short quick tests, etc.) and leads to better results in the final exams.

Furthermore, the three-level system addresses another aspect of individual feedback. First semester students tend to avoid self-assessment tests in the first weeks of the semester to avoid a negative feedback. The first compulsory test of the first semester is usually the first serious feedback students receive, and this feedback is usually rather negative. There are several reasons why the first test is negative, one important reason being the lack of training of the examples in different versions.

3.2. Solution approaches

To address these challenges, several aspects are considered in the three-level system. The use of an e-learning system, which provides a set of examples for students to practice with, allows for individualised, low-threshold feedback for students. This feedback is only available to the students and not to the teacher. Such examples appear partially in weekly homework and midterm tests, so that students see the benefit of practicing these examples during the semester. The first and second stages of the three-level system help to achieve this effect on students. The use of the e-learning system Möbius makes it possible to provide randomised examples and to assess students' results immediately after completion. This means immediate feedback for the students and no correction effort for the lecturer. In addition, the examples provided are randomised by algorithms, i.e. students are given the same question style, but certain parameters (e.g. numbers, functions, vectors, matrices, etc.) are varied. Such a situation forces students to practice their arithmetic skills more than with the traditional, unmodified examples. In the traditional form, students tend to read only the solution of already solved examples and in the exam, the resulting lack of skills to solve the example causes problems. The three-level system avoids such effects from the beginning since students cannot copy solutions in level 2 but need to solve their individual examples. Tomilenko & Lazareva (2020), who use a comparable CAS, have shown that this has a positive effect on students' test scores.

3.3. Additional advantages

Students have constant access to the pool of examples provided via the e-learning system. In addition to the weekly homework, the examples are used to assess the basic knowledge (Level 1) and to prepare for the mid-term tests during the semester. This continuous training of the focused topics provided in the assignment definition of the examples prepares students for the final test of the course at the end of the semester. In the traditional framework, exercises during the semester and final exam were considered as two different parts. In the three-level system, the skills required for linking learning outcomes (Level 3) contribute greatly to the skills required for the final exam.

In addition to the advantages in the learning process of the students, the lecturers also benefit from this system. They receive constant feedback on the students' current level of knowledge and can react accordingly. If repetitions or question rounds in the lecture or tutorial seem helpful, they can offer such measures in the course.

4. First Analysis of the results of three-level system courses

This section presents and compares the results from exercise courses between 2019 (113 participants) and 2022 (91 participants) to show an initial trend of the impact of the introduced three-level system. These years were chosen since the three-level system was introduced after 2019 and 2022 provides the most up-to-date results after three years of running the three-level system. The data was collected and obtained from the student administration system of TU Wien.

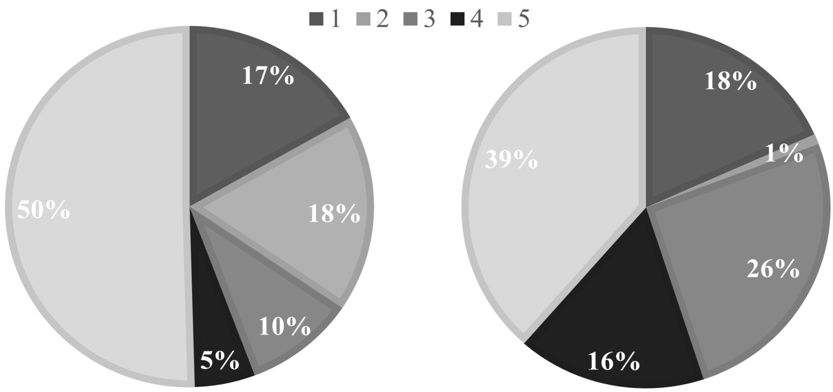

Figure 3. Grade distribution (best "1" to worst "5" grade) of the exercise courses of 2019 (left) and 2022 (right).

Figure 3 shows the grade distribution of the exercises course of Mathematics 1 in the summer term 2019 and 2022 respectively. In both diagrams, "1" corresponds to the best possible grade, while "5" means that the course could not be completed successfully. While in the summer term of 2019 only 50% of the participant of the exercise course were able to pass, this percentage increased to 61% in 2022.

A first analysis of the grade distribution of the final lecture exam also shows a positive trend in the results between the years without and with the introduced three-level system. This tendency with regard to the influence of the three-level system is visible in the overall results, but is not easily verifiable statistically, since students in Austria do not have to take the final lecture exam immediately after attending the exercise course.

5. Discussion

The three-level system is introduced as an approach to address students' challenges due to mathematics education deficits in the first semester of STEM studies, in accordance with the observations of Pinto & Koichu (2022). However, challenges in the transition from secondary to tertiary mathematics are not only related to a lack of skills. They also concern the interaction and communication between higher education teachers and students, as well as the different experiences of students during the transition phase due to different characteristics such as race, gender, sexual orientation or cultural background, see Nasir et al. (2012), Rodd & Bartholomew (2006). Therefore, further development and investigation of the three-level system and continuing teaching methods with respect to these aspects is required.

As mentioned in section 3, automatic grading of randomised exercises with the e-learning system Möbius counteracts the increased workload for the teacherNevertheless, the development of examples, including the initial idea, the layout, the algorithm behind the actual exercise, the meaningful randomisation and the grading code is a time-consuming process. Introducing an e-learning tool therefore takes time at first for the initial development, but offers many advantages for teachers and students, e.g. individual, immediate feedback, the constant possibility to access the pool of examples and to observe the learning progress of the students.

To get a first impression of the impact of the three-level system on student results, the grade distribution of the 2019 and 2022 exercise course is presented in section 4. It shows a positive trend in the development of student results based on the increased number of participants who passed the course after the introduction of the three-level system. As the comparison is limited to two years, the positive influence needs to be further substantiated by examining the results of other semesters using more informative statistical methods. Furthermore, the exact analysis of the impact of the three-level system on the final lecture examination needs to be further investigated beyond the positive trend. When merging the results of the exercise and lecture, cohort statistics are required in order to include students who have taken examinations beyond their year group.

It is planned to introduce the presented three-level system in other courses at TU Wien, e.g. in courses of Linear Algebra for Technical Physics. To this end, the approach must be adapted to the corresponding topics, e.g. include basic matrices and vector arithmetic in the basic level. In addition, this subject raises requirements for the automatic evaluation of examples, e.g. ambiguous answers such as the evaluation of an orthonormal basis of a vector space, which can consist of vectors of different order or linear combinations. Therefore, the example pool and the corresponding grading library need to be further developed.

References

Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher Education* 32, 347–364. doi: 10.1007/BF00138871.

Dlouhá, D., Pospíšil, L. & Dlouhá, K. (2022). High school mathematics knowledge level of technical university students. *8th International Conference on Higher Education Advances (HEAd'22).* doi: 10.4995/HEAd22.2022.14268.

Geisler, S., Rolka, K. & Rach, S. (2023). Development of affect at the transition to university mathematics and its relation to dropout — identifying related learning situations and deriving possible support measures. *Educational Studies in Mathematics.* doi: 10.1007/s10649-022-10200-1.

Jankvist, U.T. & Misfeldt, M. (2021). Old Frameworks - New Technologies. *Canadian Journal of Science, Mathematics and Technnology Education.* 21, 441–455. doi: 10.1007/s42330-021-00164-4.

Körner, A., Winkler, S., Pöll, C. & Breitenecker F. (2014). Erlangen von Verständnis und Erlernen von Fertigkeiten in der Mathematik einmal anders. *Zeitschrift für Hochschulentwicklung*, 9(4), 101-115. doi: 10.3217/zfhe-9-04/07.

Nasir, N. S., Snyder, C. R., Shah, N. & Ross, K. M. (2012). Racial Storylines and Implications for Learning. *Human Development*, 55(5-6), 285-301. doi: 10.1159/000345318.

Pinto, A. & Koichu, B. (2022). Diverse perspectives and experiences of university mathematics teachers on improving the secondary-tertiary transition. *Educational Studies in Mathematics.* doi: 10.1007/s10649-022-10196-8.

Rodd, M. & Bartholomew H. (2006). Invisible and special: young women's experiences as undergraduate mathematics students. *Gender and Education, 18:1,* 35-50, doi: 10.1080/09540250500195093.

Rylands, L.J. & Coady, C. (2009). Performance of students with weak mathematics in first-year mathematics and science. *International Journal of Mathematical Education in Science and Technology*, 40(6), 741-753. doi: 10.1080/00207390902914130.

Tomilenko, V. A., Lazareva, E. G. (2020). Effective Use of a Computer Grading System for Teaching Mathematics at a University. *ITM Web Conference,* 35, 03017. doi: 10.1051/itmconf/20203503017

Voskoglou, M. (2019). Comparing Teaching Methods of Mathematics at University Level. *Education Sciences,* 9(3), 204. doi: 10.3390/educsci9030204.

Wang, X., Su, Y., Cheung S., Wong, E. & Kwong, T. (2013). An exploration of Biggs' constructive alignment in course design and its impact on students' learning approaches. *Assessment & Evaluation in Higher Education*, 38(4), 477-491, doi: 10.1080/02602938.2012.658018

Winkler, S., Körner, A. & Urbonaite B. (2012). Maple T.A. in Engineering Educations. *IFAC Proceedings Volumes,* 45(2), 906-911. doi: 10.3182/20120215-3-AT-3016.00160.