Ömer Genc (2020). STACK for mathematics in engineering: concepts and effects for teachers and students. In: Contributions to the 3rd International STACK Conference 2020. TTK University of Applied Sciences: Tallinn, Estonia.

STACK for mathematics in engineering: concepts and effects for teachers and students

Ömer Genc[1]

Abstract: This paper describes the work to develop digital tasks with STACK to support tutors and students in mathematical courses for engineering in the first two semesters. The tasks will be created within the project TU-WAS at the Technical University of Darmstadt (TU Darmstadt), where it is intended to design, test and evaluate digital tasks for various implementation scenarios with different potential effects for both, tutors regarding their work in exercise-units and students regarding their learning behaviour and phases of self-study.

Keywords: computer aided assessment, mathematics for engineering, STACK, digital task design, feedback.

1 Introduction

Learning mathematics is perceived as an obstacle by most of the engineering students, especially in their first two semesters at the university. The difficulties in learning mathematics among first-semester students are mostly characterised by heterogeneous and deficient knowledge in school-math [AW14]. The lack of basic knowledge in math leads to both a higher dropout-rate from university and to lower grades in exams [HS17]. The dropout-rate from students with engineering-subjects in German universities due to the difficulties with not having a proper prior knowledge in mathematics are measured by Heublein and Schmelzer between 31-48%. It is shown that students mostly have problems with procrastinating and that there is no regular learning and exercising during the semester [Sc13]. Schulmeister pointed out that "independent learning is the weak spot of the Bologna-Concept [and that] universities are not prepared to support learners in the process of self-study" [Sc13].

Due to the high number of first-year-students in mathematics courses for engineering, it is challenging for teachers and tutors to give an adequate and individual feedback to each of them [FW16]. Given the fact that feedback lacks in quantity and quality [FW16], it is no surprise that self-study and independent-learning cannot be developed and encouraged. Feedback, in particular individual feedback, is crucial for supporting learning and increasing motivation [HT07]. Using digital tasks to provide an individual feedback is the reason to focus on computer aided assessment.

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The development of this computer aided assessment for supporting university courses (i.e. Mathematics I for Mechanical/Civil-Engineering) leads to different research interests concerning the effects of digital STACK-based tasks on tutors regarding their work and on students regarding their learning behaviour, depending on different deployment scenarios. Two different scenarios and the research interests will be further described within the following chapters.

2 Current situation of tutors and engineering first-year students

In order to support the students in their learning process and to encourage their self-study, it is necessary to have a closer look to the existing instruments and to examine the current mathematical knowledge of engineering first-year students at the TU Darmstadt.

In the course *Mathematics I for Mechanical Engineering* (ME) from the winter semester 2019/20 there are approximately 35 students in each of 20 exercising groups, which leads to a total number of first-year students in ME to approximately 700 students. One exercising group is structured in a way that there are group-exercises in which the students work on different tasks in small groups with the help of a tutor. Furthermore, the students get home exercises which must be done, in order to get bonus points for the exam. These home exercises are corrected by the tutors. Due to the high number of students and of the limited time tutors have got, it is not possible to give proper feedback and especially individual and diagnostic feedback to all the students [FW16]. The correction of the home exercises is mostly done concerning a correct or a wrong answer. Another big issue is cheating, for example plagiarizing the home-exercises from other students, which leads to inaccurate valuation concerning performance and knowledge shown in the tasks handed in.

To examine the current situation of students and tutors in the exercise-units and to be able to emphasize a potential desire of relief in their work, a survey with 19 tutors from the course was made. Three exemplar items are given below from the survey which was structured as a five point Likert-scale with "Totally agree" and "Totally disagree" on each end.

- 50% totally agreed with "I needed more time for the correction of the exercises than I initially planned."
- 62% totally agreed with "I would like to give more feedback, especially individual in my correction."
- 67% totally agreed with "The more I comment (i.e. giving feedback) an exercise, the less questions I got asked from the students."

These exemplar items suggest that the tutors possibly cannot satisfy the need and their desire of giving adequate feedback due to the given time they have got for their students. One of the benefits of giving proper feedback in exercises is that tutors might have a better time management in their exercise units. To support the students in learning and the tutors in working, the project "TU-WAS" was created at the TU Darmstadt.

3 Project "TU-WAS"

The project TU-WAS[2] started in August 2019 and is funded by the Hessian project "Digital based teaching and learning in Hesse[3]", whose aim is to give students access to quality assured and free digital learning content. The goal of the TU Darmstadt in the TU-WAS project is to design, test and evaluate a collection of digital tasks. The digital tasks are used as a digital learning environment for supporting mathematical courses for engineering students in their first two semesters.

TU-WAS is an acronym for "**T**echnische **U**niversität Darmstadt – **W**ebbasierte **A**ufgabendatenbank mit **S**TACK" and can be translated to "Technical University of Darmstadt – webbased tasks via STACK". The acronym "TU-WAS" can also be translated in German as *Do something* which indicates one of the goals of the project: students need to do *something* in order to be successful.

3.1 Prior experience with STACK at the TU Darmstadt

The usage of STACK, as the usage of all digital content in Darmstadt, is managed and organised with the learning management system Moodle. STACK was first introduced in 2016 at the department of mathematics and has been used since then in the mathematical preparatory courses for the STEM-subjects with approximately 800 participants each year. The main purpose for using STACK is to deliver the students an adaptive feedback referring to their answers and their possible mistakes in order to suggest to them specified modules to work on. Using feedback, related to the individual inputs, can highlight individual deficits [Sc19] and is able to provide self-monitoring processes in-the students.

While using STACK, one of the main research topics are the possibilities in increasing the validation and the potential diagnosis through digital tasks [Sc,19], based on the theories of "elementary-testing" [Fe17]. It was shown, that STACK has potential to support in identifying typical mistakes [Sc19] and in having a higher validation for checking different intended processes within the generated tasks in comparison with ordinary Multiple-Choice tasks [SJ17].

3.2 Implementation of STACK tasks

The main goal for the project is to support students in initiating and strengthening the self-study and increase the motivation which is possible by giving a well prepared and individualised feedback [HT07]. First, the main target is the course *Math I for ME*, where the central topics are fundamentals (basic arithmetic, functions, set-theory), traditional differential & integral calculus and linear algebra.

[2] Further information can be found at https://www.tu-was.jetzt

[3] The correct name of the project is DigLL: "Digital gestütztes Lehren und Lernen in Hessen"

In weekly exercise units the students work in small groups on various pen and paper tasks (group-exercises) with the help of the tutors. Beside these group-exercises, the students have to hand in home-exercises, which has to be done within a week. The generated STACK-tasks will be embedded in the usual exercise-units where they can be used as digital home-exercises (Scenario A). Each of those STACK-tasks used in home-exercises has to be done individually. In order to prevent cheating, randomized variables are used in these tasks. In a digital learning environment, the students have the possibility to use tasks for their own self-study in order to repeat specific contents from the course (Scenario B).

In Figure 1, these two scenarios are shown in comparison with a usual structure of a course without using STACK. The green marked elements represent the new activities created through this project.

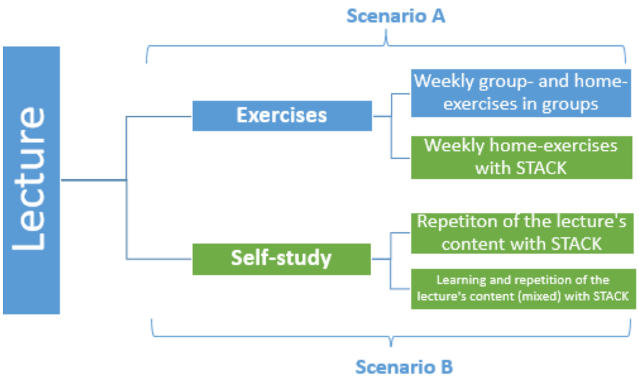

Fig. 1: Deployment scenarios

Tasks embedded in these two scenarios vary with respect to the amount of feedback given and the way the task is formulated. While designing and embedding tasks for a specific scenario, it is necessary to distinguish between tasks for learning, for performing and for diagnosis [Lu12]. The distinction between these three characterisations of a mathematical task is needed for deciding when to develop, and to use which task in which scenario.

3.3 Task design

To implement tasks in a digital learning environment it is not necessary to reinvent the wheel, but to have a closer look at tasks used in prior courses. In this case, the tasks used in the course *Math I for ME* from the winter semester 2019/20 were examined, whether they can be used as a digital task. The main issue while questioning the potential of digitalisation of a task is to examine, what students need to do for the purpose of solving the task. Therefore, tasks including problem-solving, proofing, showing a mathematical theorem or arguing cannot be used as a digital task, because they cannot be corrected automatically and would not offer any added value while using STACK. To prepare suitable new digital tasks for the project and to modify existing paper-pencil tasks to digital tasks, all 237 tasks used in the course were examined and distinguished between the different actions that are demanded to solve the task. In Figure 2 these different actions are shown with their frequency of appearance.

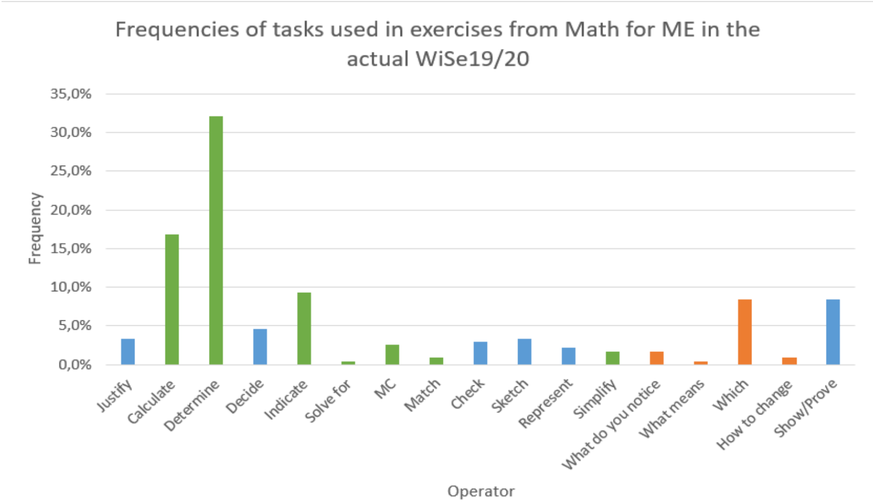

Fig.2: Frequencies of action within tasks used in exercises from the course *Math I for ME* in winter semester 2019/20

The green marked actions (60%) are tasks that can be implemented as a digital task. The blue marked actions (25% of all tasks) cannot be realized yet in a digital environment, because they focus proofing, arguing or problem-solving (this includes the action *decide* in this case. The orange marked actions (15%) depend on the given task, whether the task is suitable or not (e.g. are algebraic answers expected or is it necessary to argue). It thus appears that 60% to 75% of the examined tasks are suitable for a digital environment. In this way, it is possible to outsource basic calculation tasks as digital STACK tasks to achieve both a relief of the tutors regarding correction and the use of the benefits STACK has. STACK being connected to the computer-algebra-system maxima provides a variety of possibilities in diagnosis and support. It is possible to consider different types of tasks:

- tasks for *learning*, e.g. training scenarios or repetition of content from the course
- tasks for *performing*, e.g. preparation for final exams
- tasks for *diagnosis*, e.g. evaluating deficits

The differentiation between the types of tasks can be realized not only by how the task is written but also of the quantity and quality of the given feedback. The way feedback is implemented in a task and how it is dealt with the student's answer allows to use a task for learning and for diagnosis. Possible mistakes can be diagnosed with STACK and the students might get to know what exactly she or he did wrong. In cases where the mistakes might be obvious, e.g. using the correct formula incorrectly, the feedback can be given explicitly. The feedback can also be used to simply highlight mistakes implicitly, as shown in figure 3. In this task the students need to find a function with specific characterisations [Ka16].

Give an example of a function $f(x)$, which is continous but not differentiable at $x = 0$ and has an extremum at $x = 4$.

$f(x) =$ x-4

Ihre letzte Antwort wurde folgendermaßen interpretiert:

$$x - 4$$

In Ihrer Antwort wurden die folgenden Variablen gefunden: $[x]$

Your function does not have an extremum at $x = 4$. Also your function does not have any extrema at all.

Your function is in fact continous at $x = 0$, but also differentiable at $x = 0$, which should not be.

Maybe you mixed up zeroes with extrema. Nonetheless you should look up the necessity of an extremum and what that means for a function.

Fig. 3: Example of a feedback with no further hints

Regarding the process of learning through a task and with the given feedback, the feedback can be expanded in a way of showing, what is wrong and how the task can be solved, as shown in figure 4. The feedback tree, shown in figure 5, shows the different feedback implementations for this task.

Give an example of a function $f(x)$, which is continous but not differentiable at $x = 0$ and has an extremum at $x = 4$.

$f(x) =$ (x-4)^2

Ihre letzte Antwort wurde folgendermaßen interpretiert:

$$(x - 4)^2$$

Your answer is partially correct

Your function does have an extremum at $x = 4$.

Your function is in fact countinous at $x = 0$, but also differentiable at $x = 4$, which should not be.

It is better to start with a continous function that has an extremum at $x = 4$ and to manipulate the characteristics of beeing differentiable at $x = 0$ for example with the modulus function $g(x) = abs(x)$.

Let's have a look at the quadratic function $h(x) = x \cdot (x - 2 \cdot 4)$, which is the easiest function with zeros at $x = 0$ and $x = 2 \cdot 4$ and therefore an extremum at $x = 4$.

Combine the function f with the modulus function g: $(x - 8) \cdot |x|$

We will get the following graph:

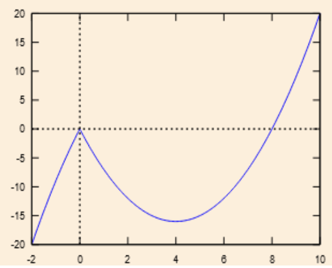

Fig. 4: Example of a feedback with a solution

In this way, it is possible to deliver different feedback (quality- and quantity-wise) based on given answers. Thus, STACK provides individualisation in the students which can lead to a higher motivation for working on tasks to establish an adequate self-study [DR93].

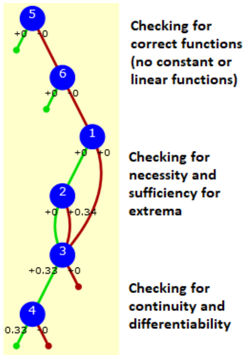

Fig. 5: Feedback tree of the shown task

4 Research interests and future work

The embedment of these tasks in scenario A and scenario B differ from each other. Therefore, different research interests prevail. In scenario A, where digital tasks will be used as home exercises, it is intended to figure out, which possible effects do STACK tasks have on the work of tutors regarding their time of correction and the structure of the exercise units. For instance, a further examination can be conducted to identify, whether there is a relief in the tutors' work, so they can concentrate more time in giving feedback due to decreased amount of printed home-exercises. In scenario B, it is important to face the fact, that students mostly work on exercises because they expect profit or obvious benefit, e.g. an overlap between tasks in exercises and tasks in tests [FH16]. This might lead into degradation from tasks for *learning* to tasks for *preparing* or *performing* [Dr10]. Same counts for tasks used in scenario A, but home exercises are usually part of a bonus-system where this kind of benefit is included. Through the given possibilities using STACK concerning individualisation, it is another major aspect to investigate, how STACK can be used as a digital medium to support learning by individualisation to support self-study. The development of suitable digital tasks in the TU-WAS project is still in progress for the these will be first used in the upcoming winter semester 2020/2021. In the future, it is planned to have surveys and interviews with tutors and students concerning the effectiveness of these digital tasks with regard to the above-named topics. One further goal of the project, besides answering the research questions, is to develop a digital collection of suitable and quality assured tasks for subsequent use, like the implementation in more mathematical courses for STEM-subjects.

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