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Enhancing Retention And Transfer Of Mathematics In Engineering Education

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ENHANCING RETENTION AND TRANSFER IN MATHEMATICS IN ENGINEERING EDUCATION PRACTICE

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ABSTRACT

This article is a reflection of a SEFI workshop on Retention. In the workshop, a SWOT Analysis has been realised of four pedagogical solutions addressing Retention in undergraduate STEM education. The pedagogical solutions are programmatic assessment, micro-credentials for online mathematics (support) learning modules, autonomous and self-regulated learning and mathematical competencies for learning. Results have provided insights into the relevance and feasibility of implementation.

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1 INTRODUCTION

1.1 Retention and Mathematics

Mathematics is at the heart of the engineering curricula and is instrumental in the engineering profession. However, one of the significant problems of engineering education is the dropout rate.

It is presumed that too little practice in mathematics creates a shallow and memorised understanding of the reasons behind calculations, and mathematics cannot be transferred. To understand mathematics, one must often practice connecting visual and symbolic representations to acquire numerical or mathematical fluency (Boaler et al., 2015).

Arguably, difficulties in higher education start in secondary school, where mathematical competencies are less developed than needed for tertiary education. To succeed in higher education, students should dedicate six hours a week to mathematics (van den Broeck et al., 2019). A criterion that is not always met. Additional stumbling blocks are caused by the many foundational mathematics courses at the start of the bachelor programme. Treacy (2016) found that these BSc mathematics courses cause a high dropout rate. As many as one-third of the student population entering STEM education fail the foundational Mathematics courses. An area for improvement is the epistemological difference between foundational mathematics and any engineering disciplines like mechanics, which typically use different symbols, representations or framings of a problem that are not or only partly compatible. It makes it difficult for higher education students who fail to recognise and know what mathematics to apply in engineering contexts. The Mathematical Competencies framework and identifications of mathematical competencies across disciplines and domains might support the cross-epistemological compatibility of mathematics in engineering (Alpers et al., 2020).

Several measures are available to mitigate the negative impact of these discrepancies, such as timely feedback, programmatic assessment, micro-credentials and learner autonomy and self-regulation. Regular and timely feedback should be used to repair any potential misconceptions or misunderstandings, adapt inappropriate learning process mechanisms or missing self-regulation activities. Effective feedback should include feed-up feedback and feed-forward mechanisms and be completed on time (Hattie & Timperle, 2007; Morris et al., 2021). Programmatic assessment and micro-credentials are two means to achieve more time on task and timely feedback (van den Broeck et al., 2019; Baartman et al., 2022). Finally, students must increasingly work autonomously and independently on the mathematics practice materials. In Covid times, we found that students highly appreciated a higher level of autonomy and felt it supported their well-being (Cristea et al., 2021). This autonomy should equally reinforce their capacity for self-directed or self-regulated learning (Schweder et al., 2022)

High shortages in STEM graduates ask for mitigating these effects worldwide as UNESCO shows mounting shortages. Creating Service Mathematics Education (SME) with the highest possible passing rate and designing it in order to enhance transfer (from mathematics to engineering and from mathematics to subsequent mathematics courses) is of the utmost importance to keep, sustain and retain as many students as possible to continue and successfully finish their engineering education.

1.2 PRIME Mathematics Education

At TU Delft, the large-scale programme of innovation in mathematics education (PRIME) has been focused on this idea for the past few years by introducing a blended learning programme for SME in which "Prepare, Participate, and Practice" is at the heart of the didactical model, activating students as much as possible towards satisfactory learning results. However, more than PRIME is needed to realise the wished-for success rate in engineering. To mitigate the low retention and looming shortages, TU Delft intends to set up an alternative support structure focused on the following:

1. Programmatic assessment (Baartman et al.,2020), making regular and formative assessment central to signalling failure and timely feedback and support to reduce dropout.
2. Micro-credential support programme, embedding online in offline education.
3. Increased autonomy for students, allowing for greater satisfaction and self-directedness in learning.
4. Using Mathematical Competencies to bridge the gap between SME and Engineering.

We are investigating the typical problems and issues in SME, the causes for low retention, and what typical shortages create barriers that limit the transfer from Mathematics to Engineering.

1.3 Workshop Assignment and Methodology

This workshop is intended for scientists and lecturers who teach mathematics and engineering. Participants are invited to interactively create a SWOT analysis of the proposed solutions. The workshop briefly introduced the theoretical foundations of mathematical learning problems in higher engineering education. Each table had a handout with "the problem definition," included in Fig. 1 and a brief theoretical explanation of one of the solutions to be addressed. Successively, the participants (teachers/researchers) attending the workshop were asked to tap into their tacit knowledge of engineering and mathematics. To make this implicit knowledge explicit to the two communities present, the participants jointly performed a SWOT analysis and presented the results to one another.

"*In an open discussion you are asked to make a SWOT analysis of one of the four approaches with the open question "To what extent does the approach meet the ambitions/solutions laid down in the formulations of the problem*?" (Fig. 1).

Formulation of the Problem

One of the major problems of engineering education is the dropout rate, often instigated by a high number of foundational courses at the start of the bachelor programme. It is stated that these may cause as high a drop out as 1/3th of the student population entering STEM education. High Shortages in STEM graduates ask for mitigating these effects. Creating SME with the highest possible passing rate is of the utmost importance to keep, sustain and retain as many students as possible to continue and successfully finish their engineering education.

The PRIME Service Mathematics Education programme has been focused on this ideal the past few years by introducing a blended learning programme in which Prepare, Participate and Practice are at the heart of the didactical model, activating students as much as possible towards sufficient learning results. However, it is found that Prime in itself is not enough to realise the wished for success rate in Engineering. We have observed a passing grade fails to consolidate the mathematics transfer to the engineering disciplines. Students, who are spending insufficient time on task cause and unsurmountable backlog, and might have passed if they did dedicate their time on task.

To turn the tables we came up with a PRIME support programme which is called RETAIN and consists of a number of activities to keep students in the engineering programme. These are:

- Create an early warning system for potential failure.
- Create programmatic assessment in which low/high stakes assessment is well-balanced and offer the opportunity for extensive feedback and progressive learning.
- Create an online programme based on math compencies (and accredited with micro-credentials) and supported by offline on campus tutor groups.

The goal is to make students

- Aware of their progress by giving student timely feedback both through feedback and assessment
- Strive for autonomous and life long learning skills development
- Aware of their highest potential in the acquistions of Mathematics for Engineering
- Able to transfer the mathematics competencies to engineering/real life situations.

To realise these ambitions we intend to make use of a number of didactical approaches, which are useful to shape supportive activities.

Fig. 1. Handout formulation of the problem for workshop

The workshop concluded with a general discussion of the solutions proposed by the audience during the workshop, testing the validity of the intended solutions developed by the authors. We expected to validate and expand on the solution space for increasing retention and supporting the transfer of Mathematics to engineering education.

2 RESULTS SOLUTION SPACE INQUIRY

2.1 The Solution Spaces

The workshop participants were devided in four groups. Each received a hand out with background information on a particular solution and the hand out of the problem definition. Included below arethe solution spaces incorporated in the hand-outs for discussion and the SWOT analysis that has been made based on the discussions and presented in the workshop.

2.2 Programmatic assessment

Programmatic assessment (Baartman et al., 2020), making regular and formative assessment central to signalling failure and timely feedback and support to reduce dropout. It is a new assessment format that has been introduced by van der Vleuten, Baartman & Schild-Mol in Dutch Higher Education. Its key principle is to make the entire growth of the student learning process visible via reliable and regular feedback tools and assessment. It provides actionable feedback, evidence of development across courses, benchmarking against learning objectives at (year/programme level) and informs remediation efforts needed to overcome gaps in student learning. The programmatic assessment does not know one type of format or way of doing things but knows many ways of realising its goals. However, a few key principles have been identified to guide the orchestration of the learning environment in one emblematic of programmatic assessment.

These principles are:

1. creating insight into the development of the student as results of different data mix of (input) points
2. each measure moment includes a feedback moment to show where the students should focus on
3. a continuous dialogue is in place to provide students with feedback for self-regulated learning development.
4. assessment is weighted, balanced and in accordance with the stakes of materials assessed.
5. the needed assessment expertise is adapted in accordance with the (high or low) stakes of the assessment.
6. validity and reliability of assessment quality are established across the entire assessment programme).

The learning outcomes are the backbone of a programme steering the multiple and balanced input points of the overall student performance towards the final requirements.Together they are offering the basis for a holistic activity and provide an assessment plan guiding the learning process.

Table 1. SWOT results programmatic assessment

Strengths • Reduce assessment load • Gives more opportunities to practice, receive feedback and demonstrate competence • Spaced assessment works well with retrieval practice	**Weakness** • Does not assess foundational competency in knowledge/skills - focus on higher level integrative skills • Does this just kick cramming down the road • Removes incentive to learn within term
Opportunity • Point to assessment or application in future courses • Creating folder/library of case studies and examples that can be integrated • Split teacher workload into separate teaching and assessment line items	**Threat** • Overcrowded students • Does it constrain study flexibility • Extra teacher workload: goes from semester limited to one year

2.3 Micro-credential support programme; embedding online in offline education

The PRIME curriculum for SME in Engineering was developed in 2017. It is a blended learning programme aiming to increase academic success, strengthen the transfer of mathematical skills to engineering, and increase engagement and participation in class via the model of prepare, participate and practice. The programme is implemented with success in x faculties across TU Delft (Cabo & Klaassen, 2019). Currently, however, with the changing environment of Higher education and increased urgency to address new developments, the programme requires improvements. These improvements are concerning, notably, the "time on task" of students, flexing the dedicated work time of students on SME and building cross-disciplinary learning communities on mathcore competencies. New technologies offer the possibility to embed online supportive micro-credit courses into the regular programme.

Micro-credentials are measurable, comparable and understandable with clear information on learning outcomes, workload, content, level, and the learning offer, as relevant. They should be designed as distinct, targeted learning achievements, and to meet identified learning needs. Compared to full-length courses, micro-credentials also offer a more personalized, on-demand learning experience. And, unlike traditional degrees, which take years to complete, micro-credentials can be completed in weeks or even days.

Offering small (cross) disciplinary (face-to-face) working groups to do additional and facilitated practice training while working on the micro-credentials will support students in establishing the needed level of "mathematical competencies". Additionally, it will allow students to refresh old knowledge when preparing for engineering courses and benchmark themselves against the required knowledge levels in Engineering Education.

Table 2 SWOT results mico-credentials

Strengths	**Weakness**
• Series of MC (refresher course) helps to bring students on the same mathlevel • MC's reactive to missing skills/competences • MC's of different size/credit • Packaging/high accessibility-> individual learning path	• Depends on self-motivation, so success is not sure • Scaffolding/interconnection of MC's is not ensured
Opportunity	**Threat**
• Not obligatory/mandatory • Opportunity to gain credits. • Confidence gained by attaining a sense of achievement upon completion plus through interaction with other cross-discipline students. • Archive knowledge	• MC does not provide the full picture. • Engineering students might not make the connection between credentials … and application.

2.4 Increased autonomy for students; Satisfaction and Self-directedness in Responsible Learning.

Learning in the Higher Education Context is said to occur when the learner can do or knows something not known before, and them are able to demonstrate the learned task on demand, independently and to a satisfactory level (Sadler, 2010). Creating autonomous engineers capable of lifelong learning requires continuous and independent judgement of the level of work delivered and whether this is good enough in a particular context. Evaluative judgment is determined by different aspects such as context, quality, standards, and assessment criteria (Fischer et al. 2023). Context is the disciplinary paradigms (ways of working) students should know. This context allows students to develop results that contain suitable characteristics for a particular (disciplinary) domain. Quality and standards allow the students to be aware of what makes a good quality performance defined by specific standards. This continuous and independent judgement of (professional) performance is called evaluative judgement. Students are expected to become more self-directed in their learning and obtain more insight into what they are capable of in mathematics or still need to learn, as well as how it translates to the engineering curriculum. A secondary spin-off might be that students will become more motivated as they become more autonomous in their learning (Cristea et al., 2021) and experience more well-being due to increased flexibility in the curriculum. Thus, evaluative judgment is the capacity to judge the work of oneself and others, which implies developing knowledge about one's assessment capability (Fischer et al.2023). According to Sadler (2010), it would require the development of substantial evaluative experiences in Higher Education Teaching contexts to enable students to acquire tacit and explicit knowledge that will help them to recognise and judge the quality of their own and other work when they see it. Only then can the learned be demonstrated independently without support. This group came up with a solution within the frame of autonomous learning and made a SWOT on *‘ a mandatory course like “learning to learn” fostering selfregulated learning (SRL)’*

Table 3 SWOT Results- Self Regulated Learning

Strengths • Transferable skill	**Weakness** • Align with teacher, adapt to courses
Opportunity • Mandatory-> for all students -> develop and improve the course	**Threat** • Retention of learned SRL skills • Workload for students and teachers

2.5 Using Mathematical Competencies to bridge the gap between SME and Engineering

The Mathematical Competency Framework is developed by Alpers and Holgjeard (2020) and offers a set of 8 competencies representative of Mathematics learning outcomes across different levels of performance in Education, ranging from secondary to higher education. Some studies have been done by the SEFI sig Mathematics in Engineering education and can be found on their webpage. The framework as a tool will provide a solid basis for formative feedback as each mathematical competency allows for setting goals where am I going (feed up), how am I going (feedback), and where am I going next (feed-forward) on the

- Task level (how well the task is understood),
- Process level (what process is needed to perform a task),
- Self-regulation (directing one's actions) and
- Self -level (personal evaluation and affect about individual learning)

following Hattie and Timperley's (2007) model of feedback. Furthermore, the mathematical competency framework allows for curricular design, calibrating secondary, SME and engineering education mathematics programmes. In this project, we will start with the SME in support of the Engineering Sciences, in which four faculties will be involved. The curricular design will be realised in close collaboration with teaching staff of the different engineering departments and mathematics teachers, as well as the involvement of students to make it apt for the local contexts. Eventually, the conceptual model of embedding (mathematical) core competencies in education as guiding framework for flexibilisation can be extended and used elsewhere.

Table 4 SWOT Results – Mathematical Competencies

Strengths • The four levels of feedback focus are highly appropriate, with support for mathematics understanding as well as helping students to develop as learners. Great! • Collaboration between the mathematics	**Weakness** • Appropriate combination of digital (automated) feedback and 1 on 1, personal feedback

teacher and those teaching the engineering courses!
• Allows for long term learning goals
	• Try to understand the situation from the students' point of view (qualitative understanding)
	• Since a passing grade does not imply required understanding, consider how the mathematics courses are assessed.
	• Mentoring activities during course:
	  o Small task to meet teacher/assistant
	  o Follow students progression

Opportunity • The problem formulation does not really capture the aim,"highest possible passing rate" should be replaced with "the necessary and active mathematics competence and skills and self-awareness to learn" • Adaption to different study programs seems not be an option? That could make math feel more relevant to students	**Threat** • Requires a lot of collaboration over a long time, can be hard to sustain for teachers •

2.6 Reflection on Results

In proposing these solutions for retention and transfer, key areas of attention were increasing the time on task and creating bridges between mathematics and engineering. In realising the SWOT analysis, the participants have shown us that programmatic assessment, micro-credentials and the mathematical competencies framework with feedback might be the most effective for retention. However, at the same time, the feasibility of effectively embedding this measure is questionable. It raises issues with the quality/assessment of the acquired knowledge, study load and overcrowdedness of curricular programmes, not to speak of the staff load and pressure to maintain a parallel or integrated programme. The good news is that cross-boundary work amongst teachers and students is facilitated through each of these solutions, allowing for flexible learning, long-term goals, building a case archive and more practice opportunities. These benefits suggest that transfer from mathematics to engineering may be stimulated but is not guaranteed.

Autonomous learning might be stimulated by better-guiding students in learning to learn. It is an important skill to acquire for later professional life. However, it also requires a different kind of teaching, as sustaining it is not a one-sided affair. The teacher must re-educate and grow different students and students' behaviour into scientifically rigorous and creative learners. Finally, the participants urge one to consider carefully how to ask the right questions and solve the right problem. One cannot solve this puzzle by focusing solely on memorisation or understanding. From educational research, we know that memorisation involves the process of encoding information into one's memory, aiming to retrieve it correctly later. Understanding, however, requires students to make sense of existing knowledge and integrate this knowledge in a meaningful context (Kirschner et al., 2006). It is assumed memorisation is improved by repetition, but independent from understanding, it leads to students failing to apply knowledge in new contexts and problem-solving situations. When students also understand the material, the likelihood of encoding it in long-term memory increases, allowing for easier retrieval. The pair memorisation and understanding are equally essential in learning, where memorisation, increases retention and understanding, improves comprehension, and application (Wang et al., 2017).

2.7 Limitations

This workshop aimed to unearth tacit and theoretical knowledge. However it is not meant or conducted as scientific study. Rather as a pragmatic exchange of information. The results in this paper should be weighted and considered as such.

3 CONCLUSION

In this workshop we presume participants have explored the barriers and problems encountered in service mathematics, and math in engineering and the transfer between those fields from their respective and experienced perspectives. The workshop has offered four choices which have been reported about in the literature to contribute to mathematics learning and transfer. These were programmatic assessment (Baartman, 2020), time on task via micro-credentials (van den Broeck (2019), Baartman (2020), mathematical competencies (Alpers, 2020) and autonomous and self regulated learning (Wallin et al.2018, Cristea et al. 2021). Participants have responded to these four solution spaces and contributed from their experiences about the applicability and relevance of the solutions through a SWOT analysis. Programmatic assessment, time on task via micro credentials and mathematical competences are seen as potentially relevant methods to achieve a higher retention. These methods should support memorisation and understanding, albeit a lot of drawbacks are present and implementation feasibility is questioned. Autonomous and self-regulated learning are seen as key-skills towards a better acquisition of Mathematics in Engineering Education and should be taught irrespective of the retention dilemma. The exchange contributed to a better insight in the pro andcons of pedagogical measures in Engineering Higher Education practice.

4 SUMMARY AND ACKNOWLEDGMENTS

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