ENHANCING RETENTION IN MECHANICS THROUGH THE IMPLEMENTATION OF PRODUCTIVE FAILURE DIDACTICS

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ABSTRACT
With the introduction of the new bachelor in 2021 all courses underwent a revision to promote, amongst other, an autonomous learning attitude. The conventional approach of teaching engineering relied on direct instructions and problem-based learning and proved to be inadequate, as students struggled to apply their engineering knowledge in capstone design projects.
To align with the new approach and to increase the application of engineering in capstone design projects, "productive failure" was introduced as a new didactical approach within our first-year course, Understanding Product Engineering. The approach engages students in active problem-solving, with the goal to increase the retention time of the theoretical concepts.
To evaluate the retention time of engineering knowledge, we developed a test to measure students' retention time over the different cohorts after one year of the first-year engineering course. During the second-year engineering course we started with an in-class formative entrance-test. An online multiple-choice test was created using questions mirroring those from the first-year final exam. 245 students performed this test, of which 16% were repeaters, and 11% transitioned from the previous bachelor programme.
The retention of knowledge reduces with each cohort, but some knowledge more than other. Especially questions with a lower Bloom's level seem to stick more. When going to higher level questions we see a decrease in retention over all cohorts. We also notice that students from newer cohorts seem to be more confident in answering higher-level questions while making as much mistakes as the other cohorts. This could be an indication that students are more confident to try even knowing that they might fail.

Keywords: Autonomous learning, productive failure, direct instruction, retention, product engineering, engineering mechanics

1 INTRODUCTION
With the introduction of the new Industrial Design Engineering (IDE) bachelor in 2021 all courses underwent a revision to promote, amongst other, an autonomous learning attitude [1]. The conventional approach of teaching engineering relied on direct instructions and problem-based learning and proved to be inadequate, as students struggled to apply their engineering knowledge in capstone design projects. To have an insight of the application of our taught engineering topics we send out a questionnaire to the coaches from the bachelor capstone project (Design Project 5, IOB6-1). We had 8 responses from the coaches which reflect the work of about 80 to 90 bachelor students. Based on the results from this questionnaire, none of the student's showed any reference to mathematics, and few to mechanics, materials, and manufacturing processes in their final report (figure 1). The cause of the low referencing of engineering knowledge in student's capstone projects is diverse and depends amongst others on the student's interest in engineering and the background of the coach who guides the student. Other causes could be the lack of confidence of the student in applying engineering knowledge, or the retention of this knowledge over time.
To align with the new bachelor's approach in autonomous learning and to increase the application of engineering in capstone design projects, "productive failure" [2,3] was introduced as a new didactical approach within our first-year course, Understanding Product Engineering (UPE, IOB1-2) [4]. Productive failure flips the traditional learning process and starts with an explorative problem which students cannot solve without the right knowledge. This is followed by an instruction explaining the

missing concept. The approach engages students in active problem-solving, with the goal to increase the retention time of the theoretical concepts. We have developed our education around this using our in-house developed framework [5] which includes lectures, workshops, and instruction videos facilitating the seamless integration of this approach into our own courses and to disseminate it among our academic peers. As an example of our approach, students are given a problem involving a system of equations without prior instruction on how to solve it. They brainstorm solutions using their existing knowledge for 10 minutes, where they most likely will fail. After this, the tutor reviews their ideas and teaches the necessary mathematical methods (like the substitution method or using row operations in an augmented matrix). Then, students solve a similar problem to apply their newly acquired knowledge. This process activates their thinking, creates a need to learn, and builds confidence. The initial struggle helps retaining the concepts.

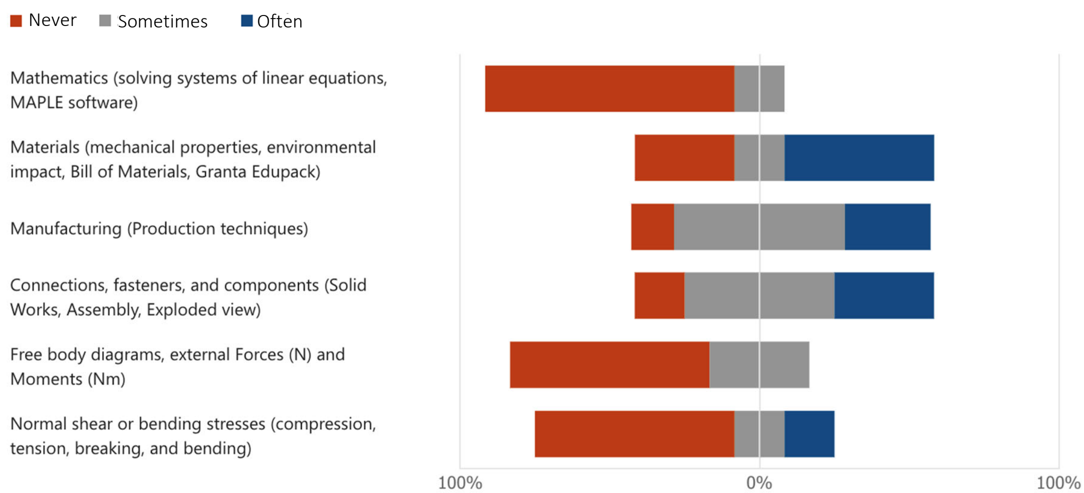

Figure 1. Overview of different engineering topics applied in capstone projects (n=8 coaches, who coach around 80 to 90 students)

Based on different literature [6-9] productive failure seems to increase the retention time but is not tested in the context of a whole engineering design course. We aim to see how well and what the second-year students remember what they learned in engineering during the previous year. For this we developed a formative Retention Time test (RT test) which is commenced during the first lecture at the follow-up course on Product Engineering, one year later. This paper will present our first formative retention-time test, the test results, and our conclusion which can be drawn on the possible retention time of our approach.

2 METHOD

During the kick-off lecture of the second-year follow-up course of Product Engineering (PE, IOB3-5) we started with a half-hour in-class formative entrance-test. This RT test was based on the final three-hour summative exam of the first-year course UPE, which took place the week before on November 8, 2023. 6 out of 10 exam questions were transformed from open questions to an online multiple-choice test, and the test was created in Microsoft Forms.
Before commencing the RT test, students were instructed to approach it with utmost care. All students in the course were seated in a large lecture hall. They were advised to maintain silence throughout the test and to complete it seriously, avoiding speculative answers. Before the start of the test students were informed about the research and asked whether they anonymously want to contribute to the research. Because the test was administered anonymously, we started with general questions which gives us insight in the year they started the first-year engineering course UPE and how well they did on its exam. After these general demographic questions students were given 6 questions mirroring those from the first-year final exam. Figure 2 shows one of the exam questions and the mirrored RT test question. Besides answering the questions students always had the opportunity to tick off the “I don’t know” (in Dutch: “ik weet het niet”) box without consequences.
The RT test consisted of 6 multiple-choice questions concerning subjects about:

1. Memorising manufacturing processes: consisting of 5 true or false statement on Shape Rolling and Die Forging.
2. Understanding of free body diagrams: consisting of nine optional Free Body Diagrams related to a stepladder against a wall.
3. Applying of mechanics of materials: where students had the choice between three beams with different cross-sections (rectangular, square, and round) made from three different materials (softwood, PVC, and low-carbon steel), and choose the option with the smallest elongation.
4. Understanding internal forces: consisting of four potential shear force diagrams related to a beam under load.
5. Understanding internal stressed caused by external forces and moments: where students had to calculate the internal shear stress and choose between 5 optional ranges (see figure 2).
6. Analysing materials: where students had to determine which material (HDPE, PP, PLA, or ABS) a product is made of based on the results of two experiments (buoyancy test and the tensile test).

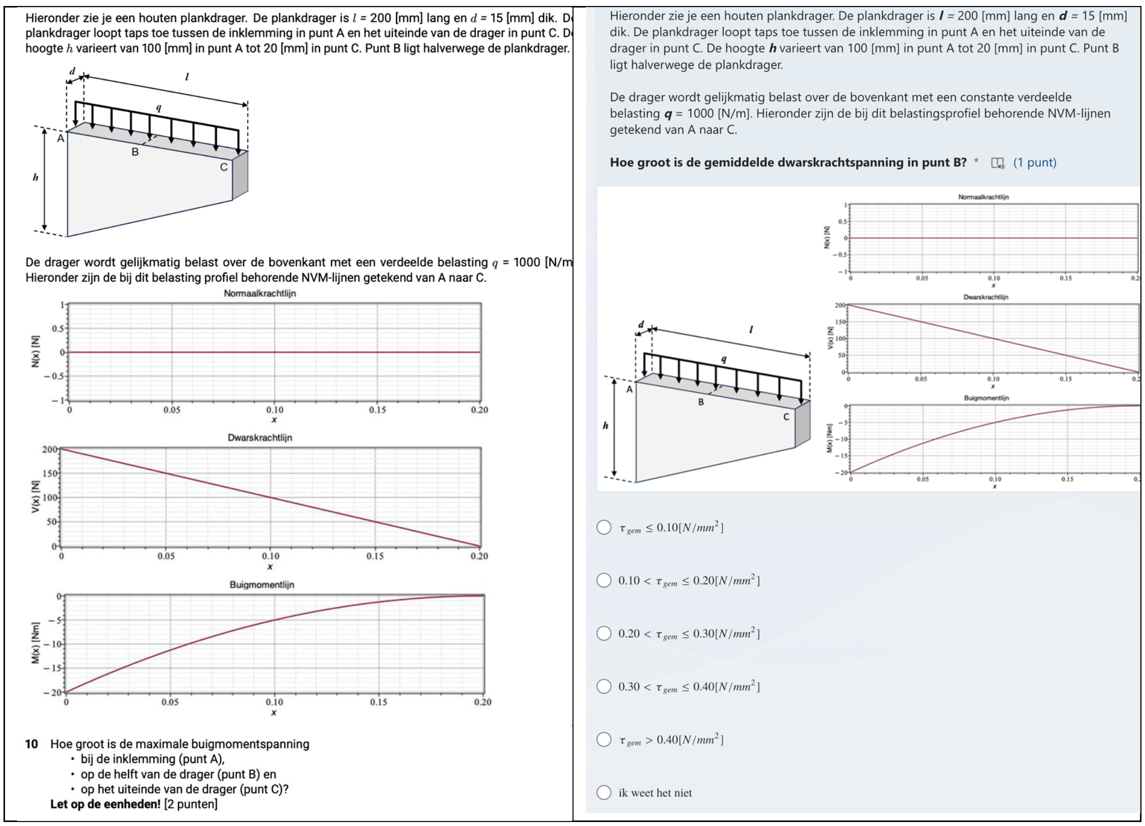

Figure 2: Comparison of the exam question (left) mirrored in the multiple-choice RT test (right)

3 RESULTS

The RT test was executed with 282 students, of which 245 indicated they were willing to contribute to the research. 73% (178) of these students were second-year students who have started their IDE bachelor the year before in 2022, 16% (39) were repeaters and started in 2021, and 11% (28) were students which transitioned from the previous bachelor programme and started before 2021. This latter group has never taken the first year UPE course and serve as a control group. They followed three separate courses on materials, mechanics, and manufacturing, not using the productive-failure didactical approach.

Figures 3 and 4 show the results of the RT test. The numbers are given as a percentage of the different cohorts, to make them more comparable. Figure 3 shows the grade for the students' last UPE exam or last Statics exam. For all cohorts it shows a similar distribution, where for every cohort approximately 40% has received a sufficient grade between 5.5 and 6.9. Figure 4 shows the results of the RT test, which shows a decrease in retention of the taught knowledge over the years. Most of the "before UPE" cohort finished the test with 1 out of 6, while most of the students from cohort 2021-2022 received one point more and that of cohort 2022-2023 even two points more. This might be an indication of loss of retention over time but does not say there is causal relation between the didactical model and the retention of knowledge.

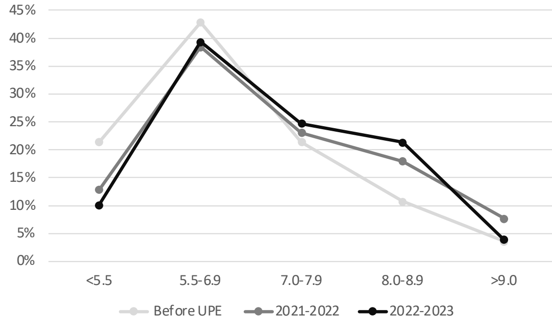

Figure 3. The indicated grade of students' last UPE or Statics exam for the different cohorts

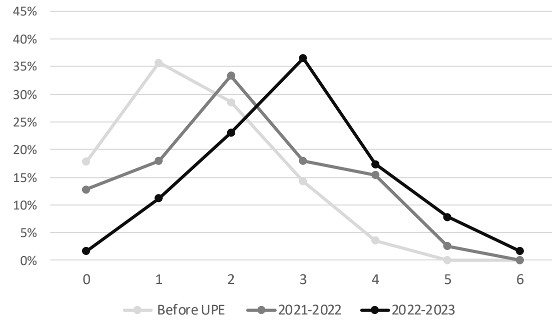

Figure 4. The results from the RT test for the different cohorts

On average the score for the test was low, with an average of 2.6 out of 6.0 points. Most points were scored on questions concerning single-concepts like manufacturing (Q1) and free-body-diagrams (Q2), see figure 5. Questions which need more procedural thinking steps like the questions on mechanics of materials (Q3) and analysing materials (Q6), or those who need more abstract and conceptual understanding like the questions on internal forces (Q4), internal stresses (Q5) are more difficult for students to retain or recall the approach.

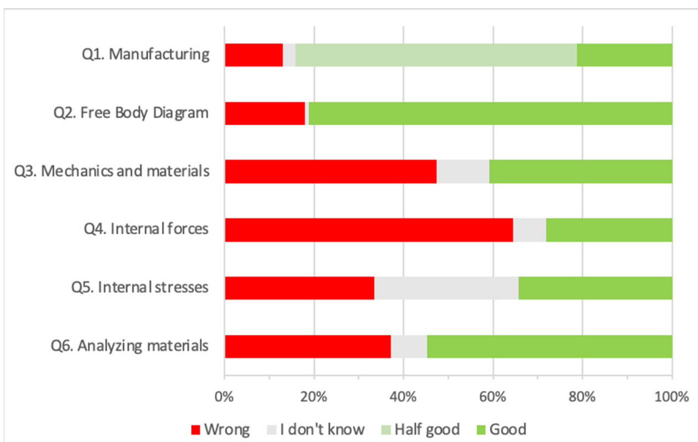

Figure 5. Results per questions for all cohorts

Figure 6 shows the results per question grouped per cohort. The difference per cohort for question 1 is not apparent. For question 2 we notice a decrease in wrong answers, where the newer cohorts scores better than the older ones. For both questions 3 and 4 the cohort 2022-2023 scores better than the other two. Less students ticked of the "I don't know" box, which might indicate they still recall parts of this concept but do not know how to approach it. Question 5 seems to be the most difficult question noticing the high number of "I don't know" ticked off. From the group who did answer this question, the students from cohort 2022-2023 shows the highest percentage of correct answers, again possible indication for recollection but not knowing how to approach it. For question 6 the number of wrong answers is the same, but most of the newer cohorts scored better on this question.

Figure 6. The results grouped per cohort for all six questions

4 DISCUSSIONS

Our research has limitations due to the educational setting. It is not possible to have a control group of students in the same cohort without the productive failure approach. All students follow the exact same UPE course and there is no identical UPE course at another university for comparison. Students volunteer to participate and do so anonymously to protect their personal data. Therefor we were unable to use data from the university grading system. We did have a unique situation because of the cohort mix entering the PE course. Cohort 2020 did not follow UPE-productive failure course and cohort 2021 and 2022 did have UPE-productive failure course. Which means we can compare these different cohorts where the "before UPE" cohort could serve as control group.

Our research also has limitations on contextual factors. The test was conducted in a lecture hall instead of an exam hall which could result in cheating, not everyone brought literature or had software available to consult during the test, the questions used in the test are a conversion from open questions to multiple choice questions, and the test was formative which could result in less serious participation or choosing the "I don't know" option.

During the UPE course of 2021-2022, several student groups were instructed by teaching assistants instead of teachers. Although teachings assistants and teachers received the same briefing, it could result in a different knowledge transfer. During the course run of 2022-2023, the direct instructions of knowledge by teachers and teaching assistants were replaced with prerecorded video's, to provide all students with equal instruction. In addition, coaches were better instructed in the productive failure didactic approach. The cohort 2023-2024 received a comparable course as the cohort 2022-2023.

5 CONCLUSIONS

We see on average no difference between the cohorts on their exam grade, but the decrease of retention overall is present. Some knowledge retains longer than other. Lower levels of learning in the Bloom's taxonomy [10] seems to stick for longer, than higher up levels. The question concerning manufacturing is on the lowest Bloom's level Memory which seems to be the most constant over the years. When going higher up in the Bloom's level we see a decrease in retention, especially on questions concerning Bloom's level of *Understanding* (question 4 and 5), and on the level of *Analysis* (question 6). We notice that the newer cohort students are more confident to answer these questions but make as much mistakes as the other cohorts. This might be a possible indication for recollection but not knowing how to approach it. This could also be an indication that students are more confident to try even knowing that they might fail.

6 RECOMMENDATIONS

The results from this test are not significantly valid to draw thorough conclusions, therefore we need more information and longer-term tests to see if there is a trend towards longer retention over the different future cohorts. We propose to do a longitudinal test to see whether students recall knowledge and skills. We therefor propose to repeat the RT test annually serving as longitudinal study of our engineering education to continuously assess and improve our didactical approach within the course, and possibly the engineering learning line in our bachelor. For this, we will devise one yearly online test which will be used in the first year and second year engineering course. The first-year test will be introduced as a formative pre-exam test in week 9 of the UPE course, where the second-year test will be introduced as formative entrance-test. With this we will be able to make a better comparison of the results on the retention, leaving out the quality of questions as a variable.

To research the application of engineering in the capstone project more thoroughly we propose to do qualitative research on the final reports of bachelor graduate students over the past 3 years and the upcoming year, including students who did not follow the new bachelor.

ACKNOWLEDGEMENT

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