

Exploring the interaction between what we learn and how we learn–

Retrieval Practice vs. Productive Failure Strategy

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Abstract:

While retrieval practice has shown to foster retention and deeper learning in psychology, there is lack of research to validate its effectiveness for disciplines like physics that demand rigorous problem-solving skills. On the other hand, productive failure learning is a new learning strategy that is more widely used in such scenarios, which aims to inculcate problem-solving skills in learners. In this study, we compared two learning strategies, retrieval practice and productive failure to ascertain if there is any interaction between the implemented learning strategy and the learning objectives: retention (memory) and problem-solving (transfer). The study employed a with-in subject, crossover design, with sixty physics undergraduate students who were randomly assigned to one of the two learning strategies and were provided with similar learning materials. Students were then tested for retention and problem-solving questions in a delayed test. We also administered self-efficacy surveys with the final test to explore any correlation between the self-efficacy score and the performance difference between memory and transfer questions. The results of the study proved that there is indeed a strong interaction between the instructional method employed and the performance for different types of questions, with retrieval practice being more effective for retention questions and productive failure for problem-solving questions. Also, a correlation was found between students' self-efficacy scores and the final test score, based on what intervention they had received.

Introduction

Research has demonstrated that depending on the subject matter and the ultimate learning goal (retention and/or transfer), one learning strategy can be more effective than the other (Gjerde et al., 2020). In educational psychological studies, retrieval practice has succeeded in producing robust results. However, when it comes to physical sciences, retrieval practice is not widely

implemented in disciplines like physics that are contingent upon transfer and problem-solving. It is feared that through retention techniques like retrieval practice students will only memorize disconnected facts without developing proper understanding (Gjerde et al., 2020). Retrieval practice involves attempting to retrieve information from memory that can enhance subsequent learning and retention. It is also known as the testing effect. Usually, in the school context, students and teachers tend to utilize testing as a tool for evaluation. However, testing also can be an effective strategy for strengthening learning. Research reveals that testing itself is an effective way to learn and achieve long-term retention relative to more traditional learning strategies such as rereading (Butler and Roediger, 2007; Butler, 2010). Experiments around retrieval practice mainly comprise three phases. In the initial study phase, participants study learning material, usually through direct instruction. In the second phase, each participant is subject to a learning condition. Those in the retrieval practice group engage in retrieval tasks such as free recall, retesting on questions similar to those in the study material, etc. In the last phase, participants complete an immediate and delayed retention test so that the efficacy of the practice can be measured (Roediger & Karpicke, 2006).

Within the retrieval practice literature, most of the studies focus on the assessment of long-term retention (Karpicke and Roediger, 2008; Abel and Bäuml, 2020; Rowley and McCrudden, 2020). However, from the perspective of meaningful learning, retention tests have limitations to evaluate the efficiency of retrieval practice on transfer tasks—tasks that involve the application of a learned concept to a novel problem (Zu et al., 2019).

On the other hand, a novel learning technique has shown promising results for transfer and problem-solving. It is called productive failure (PF) learning. It challenges the strongly held notion from numerous studies that direct instruction (DI) is a more effective instructional strategy than

discovery learning (Klahr & Nigam, 2004). Productive failure learning is based on the notion that learning and performance are not always commensurable. In other words, short-term hindrance or failure in performance can result in long-term learning if the failure is desirable and tactfully located (Kapur, 2016).

Productive failure (PF) encourages students to engage in tasks with novel concepts and fail at them as these tasks are beyond the scope of their skill set. Under certain training conditions, this process of failing has shown to improve a deeper understanding of the targeted concept and enhance learning from their failures (Kapur, 2008, 2010, 2011, 2012, 2013, 2014; Kapur & Bielaczyc, 2012). In Kapur's work (2012), PF based learning design is composed of four fundamental components: a) prior knowledge structures get triggered and adapt to the targeted concepts, b) attention is focused on the important components of the targeted concept, c) navigating and developing a detailed understanding of these features, and d) organizing and integrating these critical conceptual components into the targeted concepts. These four components are divided between Phase 1 and Phase II, where the former is associated with exploring prior concepts and identifying the gaps in their existing understanding, the latter is associated with consolidation and assimilation of the student-generated solution-strategies into the canonical concept.

In educational psychological studies, retrieval practice can enhance memory and long-term retention. motivation, another domain, can also be benefited by retrieval practice. Research reveals evidence that retrieval practice plus feedback can increase motivation to keep on studying, potentially by making one's own progress in learning more transparent and enhancing experience of competence. Competence related to self-efficacy, which means one believes himself could do something successfully or efficiently. In addition, retrieval practice may act as a scaffold for feedback and allow students to experience competence in learning, thus potentially boosting

motivation (Magdalena Abel & Karl-Heinz T. Bäuml, 2020). On the other hand, empirical research shows that students learning science through productive failure gained a deeper understanding of conceptual knowledge and produced better solutions in problem-solving cases than their peers being assigned to the conventional method. Furthermore, those students who learned through productive failures showed more positive attitudes while facing challenges and acquired a sense of ownership of their learning (Song, 2016, 2018).

Self-efficacy refers to an individual's belief in their capacity to execute behaviors necessary to produce specific performance attainments (Albert Bandura, 1977, 1986, 1997). A strong sense of self-efficacy promotes human accomplishment and personal well-being. Motivation and self-efficacy are enhanced when students perceive they are making progress toward their goals and becoming more competent. Lack of success or slow progress will not necessarily lower self-efficacy and motivation if students believe they can perform better by adjusting their approach (e.g., expend more effort, use better strategies) (Schunk, 1989). However, how can self-efficacy be improved through learning process? Do retrieval practice or productive failure help, and which can be more helpful in retention and problem-solving?

In this study, we compared retrieval practice and productive failure learning to evaluate which learning is more compatible with retention (memory) and problem-solving (transfer). We were particularly interested in looking at any interaction between the learning practice and the performance for different types of questions. Secondly, we also explored if there were any correlation and interaction between students' self-efficacy and their performance in the final test, based on what intervention (learning practice) they received.

Hypothesis of the Study

We tested these hypotheses in an undergraduate physics course

- *Hypothesis 1: There is an interaction effect between the learning conditions (Retrieval practice vs. Productive failure) and the types of problem (Retention vs. Transfer). Specifically, retrieval practice is more effective than productive failure in retention problems. Conversely, productive failure is more effective than retrieval practice in transfer problems.*
- *Hypothesis 2: When it comes to self-efficacy, there is an interaction effect between the learning conditions and the types of problem as well. In detail, students who are in retrieval practice condition show higher self-efficacy in retention problem. On the contrary, students who are in productive failure show higher self-efficacy in transfer problem.*

Methods

Participants

The participants in the study were 60 undergraduate students enrolled in an introductory physics course at a public university in USA. Most of the students did not have any previous physics coursework before. Students were randomly divided into two conditions- Retrieval practice (RP) and Productive Failure (PF). Treatments occurred in separate rooms. All tests were taken individually.

Materials

Learning Materials: Based on Zu, Munsell, and Rebello's (2019) study, two topics suitable for beginner students in physics were selected. There were two topics covered in this study: the definition of speed and energy conservation. The study material comprised a 10-minute-long lecture video for each topic. It consisted of an explanation and application part. The videos began with an introduction of concepts including definitions, formulas, and examples, followed by one example problem for demonstrating how to apply the concepts and formulas.

Assessment Materials: The evaluation test consisted of two parts: Retention and Transfer. Retention problems asked students the definition of concepts and formulas (i.e., Write down the formula for finding speed. What is the relationship between the two forms of Energy and Total Energy? There are 5 problems related to speed (Topic 1) and 5 problems related to Energy (Topic 2) in retention problems. Students received 10 points for each retention problem. Transfer problems refer to application problems that are superficially different but shared underlying basic concepts. Four transfer problems are involved in the evaluation and there are 25 points for each problem. To score the evaluation test, two different evaluators who were graduate students in physics were asked to assess students' performance. The evaluation scores correlation coefficient(γ) between the two independent evaluators was 0.90, indicating excellent inter-rater reliability. In addition, to rate students' self-efficacy, single-item self-efficacy scale was utilized. Subjects were asked to rate the following item on 7-point Likert scale: How confident are you that you will be able to solve the above types of problems related to speed/energy?

Study Design

The study employed a crossover design. To examine hypothesis 1, a between-subjects factor was the learning condition (Retrieval Practice vs. Productive Failure) with test scores on the different types of question as the dependent variables. Regarding hypothesis 2, the students' self-efficacy was measured at the evaluation phase.

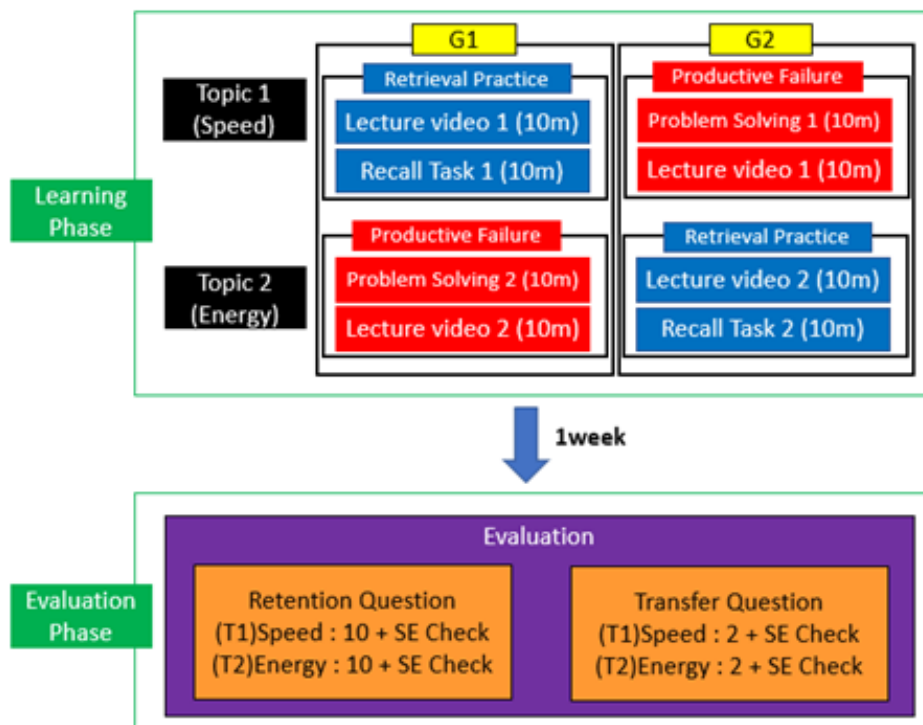


Figure 1: Schematic of the study design

Figure 1 summarizes the flow of the study process. At the beginning of the class, every student was given a brief explanation of the procedure of this study. Students were randomly assigned to two groups. Those who were allocated to the retrieval practice group watched a lecture video in a separate room at first. After the lecture was finished, students performed a recall task with problem sets which require student to retrieve learning contents. These problem sets were

consisted of recognition, recall, and execution. The feedback related with problems were given after retrieval was finished. In contrast, the students who participated in the productive failure group initially attempted to solve questions for 10 minutes about the topic they were going to learn. Following this, they watched the lecture video. Likewise, the feedback related with problems were given after lecture was finished. After learning about speed, the students continued to learn about energy. Though learning conditions were swapped, its process was the same. Seven days later, every student was given an evaluation test.

Results

Figure 2 displays the average score of evaluation test. There was a strong interaction between the learning conditions (R.P. vs. P.F.) and the types of problem (Retention vs. Transfer). Specifically, an independent t-test revealed that students with retrieval practice showed higher score than students with productive failure on the retention problems ($M = 37.32$ vs. 34.02 , $SD = 6.90$ vs. 8.43), $t(59) = 2.38$, $p = .02$, $d = 0.43$, whereas in transfer problems, students who participated in productive failure condition showed higher score than students who participated in retrieval practice condition ($M = 33.25$ vs. 38.15 , $SD = 7.49$ vs. 7.37), $t(59) = 3.72$, $p < .001$, $d = 0.66$. Overall, the results were consistent with our first hypothesis. The results indicate that students with retrieval practice performed better than those with productive failure on retention problems. Conversely, students with productive failure performed better than those with retrieval practice on transfer problems.

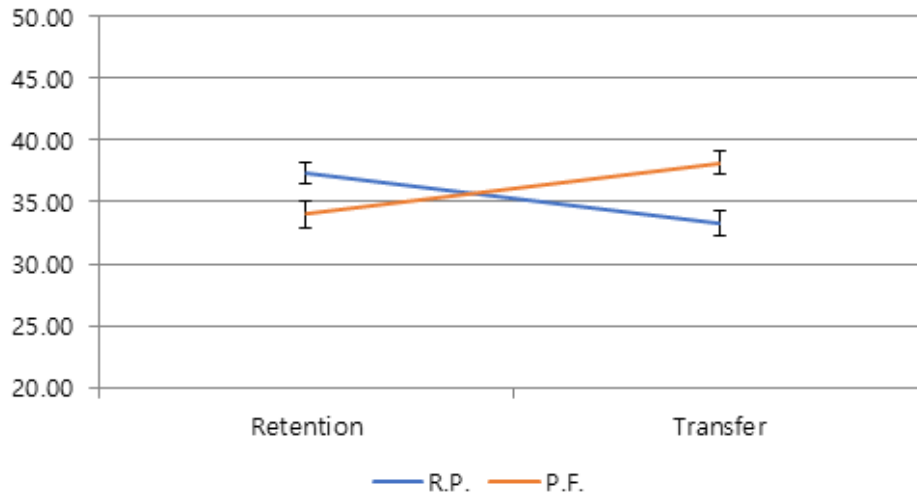


Figure 2: Evaluation test score between RP and PF groups for retention and transfer problems

Regarding to the second hypothesis, figure 3 shows the students' self-efficacy in relation to the learning strategies. Similar to score of evaluation test, there was a strong interaction between the learning conditions (R.P. vs. P.F.) and the types of problem (Retention vs. Transfer). An independent t-test revealed that students with retrieval practice rated their self-efficacy higher than students with productive failure on the retention problems ($M = 4.92$ vs. 3.92 , $SD = 1.51$ vs. 1.51), $t(59) = 3.73$, $p < .001$, $d = 0.66$. On the other hand, in the transfer problems, students who participated in productive failure condition rated self-efficacy higher than students who participated in retrieval practice condition ($M = 3.95$ vs. 4.90 , $SD = 1.43$ vs. 1.40), $t(59) = 3.79$, $p < .001$, $d = 0.67$. To summarize, the results were consistent with our second hypothesis indicative of the fact that when it comes to retention problems, students with retrieval practice showed higher self-efficacy than those with productive failure. On the other hand, students with productive failure showed higher self-efficacy than those with retrieval practice on transfer problems.

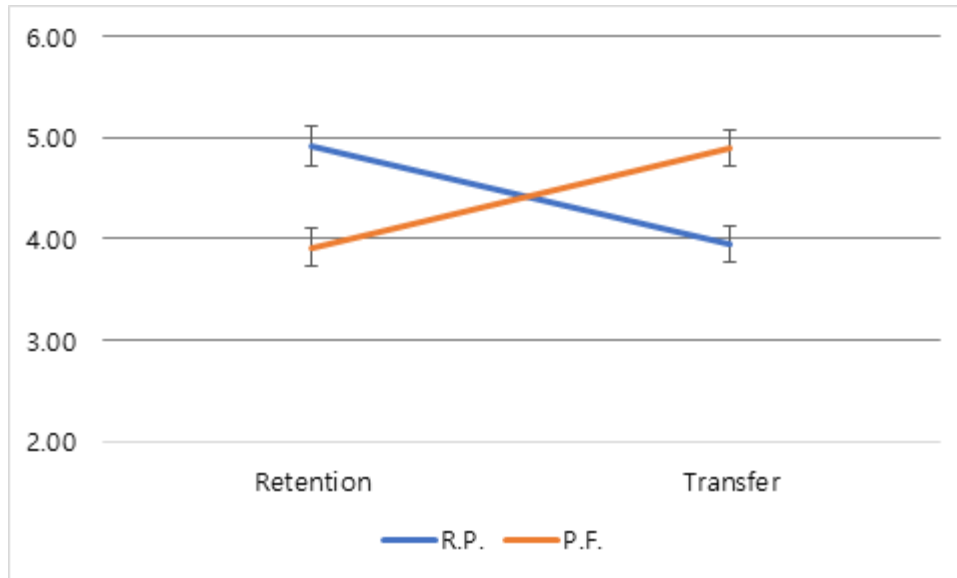


Figure 3: Self-efficacy measurement for RP and PF groups for retention and transfer problems

	Retrieval Practice (n=60)		Productive Failure (n=60)				
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>df</i>	<i>t</i>	<i>p</i>
Retention	37.32	6.90	34.02	8.43	59	2.38	0.02*
Transfer	33.25	7.49	38.15	7.37	59	3.71	< 0.001***
Retention_SE	4.92	1.51	3.92	1.51	59	3.73	< 0.001***
Transfer_SE	3.95	1.43	4.90	1.40	59	3.79	< 0.001***

* $p < .05$, *** $p < 0.001$

Table 1: Results Summary Table

Discussion

Both Retrieval Practice (RP) and Productive Failure (PF) are effective learning strategies that is useful in achieving learning objectives. However, the performance of the learning strategy

is contingent on the types of problem. In this experiment, the effects of RP versus PF on the types of problem and self-efficacy was analyzed. When it comes to performance, the learning strategies interacted with the types of problems. To be specific, RP performed better than PF on retention problems, while PF performed better than RP on transfer problems. These results are consistent with the previous studies that RP is effective for retention problems (Karpicke and Roediger, 2008; Rowley and McCrudden, 2020), and PF is effective for transfer problems (Kapur, 2008, 2010; Kapur & Bielaczyc, 2012). These results that effective learning strategies vary depending on the types of problem can be explained by transfer-appropriate processing. Transfer-appropriate processing refers to the phenomenon that performance on learning will be most effective when the student engages in learning activity that matches with the processing required during a final assessment (Kolers and Roediger, 1984; Morris et al., 1977). Students who participated in RP focused on retrieving factual and procedural knowledge. Through RP, they would retrieve the definition of the concepts, formulas, and problem-solving procedures. Such processing would be matched with the retention problems which asked them for the definition of concepts and formulas. Otherwise, students who participated in PF tried to solve problems related to novel concepts. Through failure in processing, students tried to not only activate prior knowledge but also elaborate, organize, and assemble the critical features into the novel concepts. As students recognized the critical conceptual features, they were able to recognize the similarities between the context of initial learning and subsequent transfer problems. For this reason, they successfully could solve the transfer problems.

This study also examined students' self-efficacy as well. As hypothesized, RP students rated their self-efficacy higher than PF students on retention problems. Contrary to that, PF students rated their self-efficacy higher than RP students on transfer problems. This result indicates

that students with RP showed high self-efficacy on retention problems and students with PF showed high self-efficacy on transfer problems. Such results can be explained by the theory of experience of competence (Deci, 1971; Abel and Bäuml, 2020). When students tried to solve both types of problems (Retention vs. Transfer), they differentially recognized the effectiveness of each learning strategy (RP vs. PF). As a result, when students with RP solved both retention and transfer problems, not only performed better but also experienced competence on retention problems. Likewise, students with PF were asked to solve both types of problem, they had better performance on transfer problems compared to retention problems, which can enhance students' self-efficacy by facilitating their experience of competence on transfer problems.

Although this study investigated the effect of interaction between learning strategies and the types of problems on self-efficacy, further research should be elaborated on motivational aspects. According to previous research, the effect on students' motivation may appear differently during the learning process, depending on students' goal orientation (Bell and Ford, 2007; Belenky and Malach, 2012). This result is suggestive of the possibility that the student's goal orientation may affect the change in students' self-efficacy in the learning process.

This study found that the effectiveness of learning strategies and students' self-efficacy can vary depending on the types of problems. Since the goal of education is not only memorizing the conceptual knowledge but also applying that knowledge to new situations, this study indicates that teachers and students should not succumb to a specific learning strategy. Rather, the use of learning strategies suitable for the types of problem can improve students' self-efficacy as well as their academic performance.

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Individual Paper Summaries

Hyunuk Park

1. Karpicke, J. D., Blunt, J. R., & Smith, M. A. (2016). Retrieval-based learning: Positive effects of retrieval practice in elementary school children. *Frontiers in Psychology, 7*, 350.

Karpicke, Blunt, and Smith (2016) found that Retrieval Practice was significantly better than Restudy for both recall and recognition even after taking into account students' processing speed and reading comprehension. Eighty-eight children (mean age 10 years) participated in the three experiments. Researchers measured two individual differences (Reading comprehension and processing speed). Independent variable was learning conditions (Restudy vs. Retrieval). Dependent variables were recall performance (Free recall test) in experiments 1 and 2, and recognition performance (Recognition test) in experiment 3. The researchers examined that there was the only main effect of learning conditions in recall and recognition tests without any interaction effects with individual differences. Even though the researchers used ANCOVAs to control students reading comprehension and processing speed, they should have checked there was no significant difference in these abilities between the two groups.

2. Roediger III, H. L., & Karpicke, J. D. (2006). Test-enhanced learning: Taking memory tests improves long-term retention. *Psychological science, 17*(3), 249-255.

Roediger and Karpicke (2006) found that repeated retrieval practice leads to better performance than restudy on delay retention test. In experiment 1, the researchers compared final retention scores which were conducted 5 min, 2 days, or 1 week later in both conditions (restudy and test). In experiment 2, the authors elaborated test conditions into a repeated study, single test, or repeated test group. Participants were 120 undergraduates in Exp1 and 180 undergraduates in Exp2. Subjects were allocated into three learning conditions: repeated study, single test, and repeated test. In experiment 1, restudy group performed better than the test group on 5 minutes retention test. However, in the 2 days or 1 week of delayed retention, the test group significantly performed better. Regarding experiment 2, in the immediate retention test, the repeated study group performed the best followed by a single test and a repeated test group. However, in the delayed retention that was performed 1 week later, the repeated test group performed the best followed by the single test group and then the repeated study group. In this study, a diffusion threat exists. This is because researchers conducted tests with different time intervals (5 min, 2 days, or 1 week). If each group of students had the opportunity to talk about tests, this study's internal validity would be harmed by this diffusion.

3. Rowley, T., & McCrudden, M. T. (2020). Retrieval practice and retention of course content in a middle school science classroom. *Applied Cognitive Psychology*, 34(6), 1510-1515.

Rowley and McCrudden (2019) found the effect of retrieval practice on science learning. The authors conducted an experiment on middle school students in an authentic educational setting. Participants were 39 students, aged 11-13 years old. Researchers designed between-group design.

Independent variables were learning conditions (Retrieval practice vs. Copy) and the dependent variable was final test performance (Retention). The learning material was science text which was consistent with the school science program. The researchers confirmed that the retrieval practice is still effective in an authentic classroom. Considering the goal of this research, it had limitations on its ecological validity. In a school setting, their performance is not only estimated by simple retention but also by their deep understanding.

4. Lyle, K. B., & Crawford, N. A. (2011). Retrieving essential material at the end of lectures improves performance on statistics exams. *Teaching of Psychology*, 38(2), 94-97.

Lyle and Crawford (2011) investigated the effect of PUREMEM program to psychology course. The PUREMEM procedure was developed based on the retrieval practice. As a quasi-experiment, 77 undergraduate students in the PUREMEM section and 78 in the comparison section. The authors designed 2 (Section) x 4 (Exam) mixed design. Independence variable of this experiment were learning section (PUREMEM vs. Comparison) and four exams. They measured exam score as dependent variables. The researchers examined that main effect of section and exam. They also found significant interaction in exam 1,2 and 4. To be specific, PUREMEM advantage was significant for exams 1,2, and 4. However, the authors cannot suggest appropriate explanation about their exceptional results in exam 3. Since exceptional results can serve as a steppingstone for further research, it is desirable to provide hypotheses to explain this.

5. Butler, A. C. (2010). Repeated testing produces superior transfer of learning relative to repeated studying. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36(5), 1118.

Butler (2010) found that the beneficial effect of retrieval practice on transfer tasks. The author explored whether retrieval practice could be used to promote far transfer. The researchers assessed transfer of learning to new inferential questions in different knowledge domain (i.e., how to apply characters of bat's wing into military aircraft). The interrater reliability was high ($K = .91$). Twenty undergraduate students were participated. The independent variable was type of initial learning (restudy vs. test) and the dependent variable was new inferential questions within different knowledge domains. There was significant difference between two groups and its effect size was large ($d = 0.99$). The results indicated that the retrieval of information from memory may be the critical mechanism that fostered transfer. In this study, even though the number of subjects was low ($n = 20$), it was impressive that it not only showed statistically significant difference but also a high effect size.

6. Tran, R., Rohrer, D., & Pashler, H. (2015). Retrieval practice: the lack of transfer to deductive inferences. *Psychonomic bulletin & review*, 22(1), 135-140.

Tran, Rohrer and Pashler (2015) examined whether the benefits of retrieval practice could transfer to deductive inferences. They found that the testing condition performed better on final recall test, while performance on inference questions showed no improvement from retrieval practice. In experiment 1, sixty-eight undergraduates were participated in. The Independent

variable was study conditions (rereading vs. retrieval practice) and the dependent variable was inference assessment which was conducted immediately. The results demonstrated that there was no benefit of retrieval practice on the inference assessment. The researchers conducted experiment 2 which only modified the immediate inference assessment into the delayed. Again, the authors found no benefit of retrieval practice on inference questions. In additional experiment 3, the researchers elaborated retrieval practice by requesting participants to type the missing keywords. The results were similar to Exp 1 and 2. There was no positive effect on transfer. Finally, in experiment 4, the authors changed their set of stimuli to determine whether or not the benefit came from materials. Consistently, the results showed that there is no significant performance difference between the learning conditions on the inference assessment. This paper is similar to Schwartz and Bransford (1998) that we learned in class in that it elaborated the research sequentially. By elaborating experiments step by step, the researchers eliminated alternative explanations (time interval, retrieval activity, and material).

Xinyu Zhang

Literature Review

Would you like to learn more? Retrieval practice plus feedback can increase motivation to keep on studying

Magdalena Abel*, Karl-Heinz T. Bäuml

Retrieval practice can enhance memory and long-term retention. motivation, another domain, can also be benefited by retrieval practice. This article presented three experiments. Firstly, subjects

studied Swedish vocabulary by means of retrieval practice – with or without corrective feedback – or restudy. To examine whether retrieval practice can influence motivation, they combined the typical design of a testing-effect study with an additional phase borrowed from motivation research, the so-called free-choice period. The results provide first evidence that retrieval practice plus feedback can increase motivation to keep on studying, potentially by making one's own progress in learning more transparent and enhancing experience of competence. Competence related to self-efficacy, which means one believes himself has the ability to do something successfully or efficiently. In addition, retrieval practice may act as a scaffold for feedback and allow students to experience competence in learning, thus potentially boosting motivation.

Motivation-based selective encoding and retrieval

Halamish, Vered ; Stern, Pnina

Memory & cognition, 2021-12-22

People are more likely motivated to remember certain pieces of information rather than other pieces. That's to say that motivation can more or less affect retrieval practice. This study conducted two experiments to investigate motivation based selective encoding and retrieval processes in the context of an associative memory task. There are 36 participants who studied information concerning six individuals for a later memory test. During the test, participants self-regulated their testing by deciding how to allocate test time for the different items, whether to go back and retest themselves on items, and in what order to answer them. The decisions that the

participants made during the study and the test were recorded and later analyzed. This procedure allowed us to simultaneously examine not only the effect of motivation to remember on memory performance but also the effect of motivation to remember on various selective encoding and retrieval processes. The results revealed that motivation yielded selective processing during retrieval, as rememberers allocated more time to test queries about target information that they were motivated to remember and tended to start the test with these queries. In summary, incentive-based motivation produces selective processing not only during encoding but also during retrieval.

Self-Efficacy for Learning and Performance

Schunk, Dale H.

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The theory of self-efficacy continues to be applied to a variety of educational settings and grade levels. This paper addresses various issues related to self-efficacy in settings involving academic learning and performance. The paper begins with a discussion of several conceptual and methodological issues on self-efficacy theory from previous findings. Next, to compare self-efficacy operation in learning settings with that in contexts involving performance of previously-learned behaviors, the efficacy judgment procedure was altered. For each efficacy judgment, students are presented with sample problems, questions, or tasks, for a brief time (e.g., 5 seconds) that is long enough to assess difficulty but too short to mentally perform the operations. It suggests that self-efficacy helps learning improve.

Then, the article presented a discussion of a subset that distinguishes the operation of self-efficacy during learning and its relation to other variables from its role in situations involving performance of previously learned skills. Collectively, these points suggest revisions to self-efficacy theory.

Motivation and Transfer: The Role of Mastery-Approach Goals in Preparation for Future Learning

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Mastery-approach goals facilitate constructive cognitive processes and help connect later learning episodes with relevant earlier learning which may serve as a mechanism of transfer. This paper investigated how students' achievement goals interact with different forms of instruction to promote transfer. Students were given either invention or tell-and-practice activities when learning statistics concepts and their achievement goal orientations were measured at the beginning of the experiment and the author assessed students' goals during the learning activity. Results are discussed in terms of contributions to research on knowledge transfer, achievement goals, and educational practice. It suggests that students who entered the experiment with a high mastery-approach goal orientation would be more likely to transfer, regardless of instruction. And invention activities would lead to higher mastery-approach goal adoption for the task and more attention to important conceptual features, as students would focus on trying to understand the material. Finally, because it was expected that invention

activities would promote mastery goal adoption during the task, the author found that a moderating effect of invention activities, such that there would be a smaller effect for students' initial mastery-approach goal orientation on transfer for those who invented compared to those who received tell-and-practice instruction.

Voluntary or mandatory training participation as a moderator in the relationship between goal orientations and transfer of training

Vered Halamish and Pnina Stern

Memory & Cognition volume 50, page 736–750 (2022)

Goal orientations were conceptualized in four dimensions: mastery-approach, mastery-avoidance, performance-approach and performance-avoidance (Elliot & McGregor, 2001). To date, research has reported mixed evidence on the question whether voluntary or mandatory participation is associated with higher motivation and transfer of training. Grounded in the frameworks of participatory design, the notion of autonomy in basic psychological needs theory, and the 2×2 model of achievement goals, this meta-analysis examined the relationship between goal orientations and transfer of training in contexts of voluntary and mandatory training participation with a sample of $N = 4729$ trainees in $k = 29$ studies. The meta-analytic evidence suggests that mastery-approach orientation had the highest, most positive correlation estimate with transfer, while performance-avoidance had the lowest, most negative correlation estimate. These findings highlight the important role of a mastery-approach goal orientation for influencing the use of trained knowledge and skills after training on the job. That's to say that if

trainees participated in a training program voluntarily, they are more motivated and do they transfer more than trainees who participated in a training program mandatorily.

Self-efficacy and Productive Failure

Chong Ho Yu & Hyun Seo Lee

Creating Change to Improve Science and Mathematics Education pp 101–124

Some psychologists argue that lacking self-efficacy can also affect academic performance.

Specifically, learners can cease to improve when they become content with their current skill level. The productive failure approach implemented in the Hong Kong educational system is proposed as a possible remedy to break down the ego of learners, thus making room for improvement. The author used the evidence from 2015 PISA and 2016 PIAAC indicating that the relationship between self-image and academic performance is nonlinear in nature.

Productive failure can remediate these limitations by providing students with guided discovery, collaborative project-based learning, and more importantly, turning their misconceptions and failures into positive learning outcomes. As a result, learners might acquire a false sense of competency by earning a good grade easily. However, recent research indicates that perception is not equated with performance. Open-mindedness, which is crucial to learning, requires humility.

It is the conviction of the authors that productive failure could be implemented in math and science education to improve both modesty and problem-solving skills.

Paper Summaries – Soumi Mukherjee

1. The effectiveness of concept mapping and retrieval practice as learning strategies in an undergraduate physiology course

Joseph Burdo and Laura O'Dwyer

<https://doi.org/10.1152/advan.00041.2015>

Burdo and O'Dwyer (2015) found that retrieval practice is beneficial in short term learning whereas concept mapping did not cause any substantial gain in learning. Retrieval practice encompasses recalling concepts and information from the memory that was previously encoded. Concept mapping involves representing a hierarchical diagram connecting dots amongst different pieces of information. The study's main focus was to assess if these two learning strategies enhanced exam performance and to compare if one method was better than the other. At the onset of Introduction to Physiology at a private university, two separate groups consisting of 21 students were created for each learning strategy and the remaining out of a class of 161 served in a control condition with neither retrieval practice nor concept mapping. For the intervention conditions, one group was responsible for building concept maps while the other group quizzed one another on the previous week's content. The control group received no interventions as such. This was a quasi-experimental set-up as students were not randomly assigned to conditions. The learning strategy administered is the independent variable (retrieval practice, concept mapping, control) and the exam performance scores is the dependent variable in this study. There was no significant difference in exam scores between the control and experimental groups, however, the retrieval practice group did significantly better than the concept mapping group on one of four exams. They also found that the concept mapping group continuously scored lower than the control group which led them to speculate potential limitations of the study. The experimental groups only had 21

students in each group while the control group had 102 students. The effect size ranged from low eta square ≤ 0.01 to medium effect size eta square ≤ 0.05 . The method of assessment mostly had multiple-choice questions (MCQ) which may have favored the retrieval practice group and not the concept mapping group.

Burdo, J., & O'Dwyer, L. (2015). The effectiveness of concept mapping and retrieval practice as learning strategies in an undergraduate physiology course. Advances in Physiology Education, 39(4), 335-340.

2. Productive Failure

Manu Kapur

<https://doi.org/10.1080/07370000802212669>

Kapur's (2008) main purpose of the study was to find out the role of failure in learning and problem solving. His study was designed to see if there is any effective value in solving ill structured problems without the support of external instructions and scaffold and to check if a contrasting case design can help in extracting this efficacy. The study was done in a synchronous computer supported collaborative learning (CSCI) environment where student triads from 11th grade across seven high schools in India were asked to solve either ill or well-structured physics problems. Post participation in group problem solving, the students solved well-structured (WS) problems followed by ill structured (IS) problems individually. The findings suggested that IS group discussions had more complexity and covered diverse problem-solving structures like problem analysis, problem critique and criteria development than the WS problem solving group. Though

WS had better quality of solution $M= 2.179$, $SD=1.317$ vs IS group $M = 1.420$, $SD = 1.085$, and even if they seemingly failed, the author argued that there was a hidden efficacy in their complex a divergent interaction process. When they shifted to solving both IS and WS problems individually, students in the IS group outperformed their WS counterparts ($\chi^2 = 22.82$, $p < .001$, WS problems and $\chi^2 = 27.21$, $p < .001$. IS problems), which is suggestive of delayed productivity in failure. Thus, the author argued that the latency in providing external structure to students in the IS group helped in spontaneous transfer of problem-solving skills where they analyzed different ways of scaffolding an ill structured problem.

Kapur, M. (2008). Productive failure. Cognition and instruction, 26(3), 379-424.

3. Retrieval Practice Produces More Learning than Elaborative Studying with Concept Mapping

by Karpicke, J. D. / Blunt, J. R. (2011)

Doi : 10.1126/science.1199327

Karpicke and Blunt's (2011) study show that retrieval practice is more effective to foster meaningful learning than detailed study practices using concept mapping. They conducted two experiments to establish their claim. Experiment one had eighty undergraduate students – first students studied a science text in one study session (initial learning phase) followed by reading the text in four consecutive study periods. In elaborative concept mapping experiment, they did the same thing for the initial learning phase but instead of repeatedly studying the text in next phase, they created a concept map. Finally, in retrieval practice condition they were asked study and recall the information post learning phase twice. The amount of learning time was exactly matched in

two conditions. At the end of the learning phase, the students were asked to predict the amount of information they can recall from the text in a week to assess their metacognitive knowledge and after a week they gave a short answer test. Retrieval practice condition ($M = 0.67$) outperformed the concept mapping condition ($M = 0.45$) and enhanced long-term retention above and beyond elaborative practice by a standard deviation of 1.50. They performed a second experiment with 120 students to replicate these results and used a within subject design where each student made a concept map of a science text and practiced retrieval on a second science test. They did this to see if their results are dependent on the structure of materials and determine the robustness of retrieval practice vs elaborative strategies on individual learner. They took two tests where half of the students took a short answer test and other half took the final test where they created concept maps from both the texts they had learned. From their experiment they saw that overall, 84% students performed better in the final test practicing retrieval than concept mapping. The authors thus established that retrieval practice is effective and can be generalized across texts, can be used in test questions that require comprehension and inferences from students and will also help in critical tests that involves use of concept maps.

Karpicke, J. D., & Blunt, J. R. (2011). Retrieval practice produces more learning than elaborative studying with concept mapping. Science, 331(6018), 772-775.

4. Productive failure in mathematical problem solving

Manu Kapur

<https://doi.org/10.1007/s11251-009-9093-x>

Kapur (2010) study compares instructional designs “productive failure” with traditional “lecture and practice” in a quasi-experimental set up in topics of rate and speed, a curricular unit spanning two weeks. Seventy-five participants came from a secondary school in Singapore who studied mathematics in grade 7. Students experienced either the productive failure (PF) intervention $n=37$ or the traditional lecture and practice (LP) intervention $n=38$ till the last lesson of the unit. In PF conditions students solved ill structured un scaffolded problems in groups and seemingly failed at group and individual level and had lower confidence in their solutions ($M=1.22$, $Sd=0.82$). However, in post-test conditions students in PF performed better than LP condition. ANCOVA analysis on post-test 1 scores showed a statistically significant effect of condition (PF vs. LP), $F(1, 72) = 10.69$, $p = .002$, ES (effect size) = .75. PF students outperformed the other students in traditional LP condition on well-structured problems [$PF: M=30.8$, $SD=4.09$, $LP: M = 28.9$, $SD = 5.13$; $F(1,72) = 4.87$, $p = .019$, $ES = .42$] and higher difficulty level problems [$PF: M = 7.0$, $SD = 3.60$, $LP: M=4.5$, $SD=3.55$; $F(1,72) = 8.95$, $p = .004$, $ES = .98$]. PF students also solved problems with help of scaffolding on topics of relative speed which were not covered in class.

Kapur, M. (2010). Productive failure in mathematical problem solving. Instructional science, 38(6), 523-550.

5. Is having more prerequisite knowledge better for learning from productive failure?

Pee Li Leslie Toh & Manu Kapur

<https://doi.org/10.1007/s11251-016-9402->

Kapur and Leslie (2017) performed two quasi experimental studies to examine whether prerequisite knowledge is necessary to investigate and solve problems before target concept is learnt. They did this study on the multi organizational biology concept of monohybrid inheritance. In study 1, eighty 9th grade students from a school in Singapore were either provided or not provided with the prior knowledge before the generation phase. They found that for exploring and generating complex solutions for a multilevel concept, students having relevant prerequisite knowledge had a better overall advantage over students who did not have the knowledge. Due to limitations of not having a control for prior knowledge, not measuring cognitive load in learning phase and not knowing which group had more knowledge retention a second study was conducted. The second study examined whether provision of prerequisite knowledge helped students learn from subsequent instructions. The students were randomly assigned to two groups, where the prerequisite knowledge group got an additional 3-hour lecture on previous concepts and the other group did not. Though such a provision helped the students to generate and explore solutions to the biological problem, it necessarily did not enhance learning. The representations and solution methods though were greater in number for the prerequisite knowledge group, it was not always correct. They had similar learning gains than the group without provision. The group with provision was less engaged in the lesson and had to put in more effort in the subsequent instruction. The more prerequisite knowledge provided, above what a learner already knows, is not useful for learning new concepts. They further concluded that relying on prior knowledge required low mental effort in learning new concepts than those provided with prerequisite knowledge.

Toh, P. L. L., & Kapur, M. (2017). Is having more prerequisite knowledge better for learning from productive failure?. Instructional Science, 45(3), 377-394.

6. DIY productive failure: boosting performance in a large undergraduate biology course

Chowrira, Sunita G., et al. 2019

<https://doi.org/10.1038/s41539-019-0040-6>

Chowrira et al's (2019) study examines effect of productive failure (PF) Versus active learning (AL) strategies university level introductory biology course in a quasi-experimental set up. In one course 295 students learnt topics using PF while the other group consisting of 279 students learned the same topics using AL approach. Their performance was examined in the two midterm exams, and one final exam. Students in PF outperformed the students in AL in midterm 1 (5.14 *** $p < 0.001$, 95% CI = [3.23, 7.06], $t(559.31) = 5.28$; $d = 0.44$) and final exam (7.63 *** $p < 0.001$, 95% CI = [4.75, 10.52], $t(567.02) = 5.20$; $d = 0.44$). Students in PF scored 5% higher than the AL counterpart in Midterm 1 and 2 when the data was controlled for gender, university and program. The effect was more pronounced in low performing student and lasted till the final exam where the low performing student improved more while the effect was eliminated in better performing students. The authors conclude that learning from instruction can be difficult and require higher cognitive load, whereas hands on group level problem solving in PF benefitted low performing students for whom lectures, and instruction may not be an adequate resource for complete understanding of concepts.

Chowrira, S. G., Smith, K. M., Dubois, P. J., & Roll, I. (2019). DIY productive failure: boosting performance in a large undergraduate biology course. npj Science of Learning, 4(1), 1-8.

1. **Kapur, M. (2012). Productive failure in learning the concept of variance. *Instructional Science*, 40(4), 651–672. <https://doi.org/10.1007/s11251-012-9209-6>**

Challenging the plethora of studies upholding the efficacy of direct instruction (DI), the paper uses the productive failure (PF) strategy to test the efficacy of discovery learning. The results show that productive failure is a more effective learning technique for skills such as data analysis, conceptual insight, and transfer. A quasi-experimental design was used to teach the concept of variance to 140 ninth graders. The pre-test conducted showed no significant difference ($p = .177$). The intervention comprised of four, 55-minute instructions (DI or PF), followed by an engagement survey. In the DI condition, the concept of variance was explained, and its formula was used to solve several questions. Students were also assigned homework problems for further practice. Whereas in the PF conditions, students began by solving one of the questions in groups without any prior exposure to variance, which was then followed by direct instruction. But no homework problems were assigned. Lastly, all the students took a paper-based post-test. The results showed that while there was no significant difference between the groups for the procedural fluency items on the test, students under PF conditions significantly outperformed those under DI for data analysis ($p=.002$), conceptual insight ($p<.001$), and transfer item ($p<.001$)—indicating that allowing students to explore a novel topic on their own followed by instruction is a more efficient learning strategy.

2. **Gjerde, V., Holst, B., & Kolstø, S. D. (2020). Retrieval practice of a hierarchical principle structure in university introductory physics: Making stronger students. *Physical Review Physics Education Research*, 16(1), 013103. <https://doi.org/10.1103/PhysRevPhysEducRes.16.013103>**

A common reason why learning strategies like retrieval practice are not used for hard sciences is because of the underlying fear that students will only memorize disconnected facts without proper understanding. This study puts the claim to test through an initial true experiment and a follow-up correlational study. The participants were undergraduates enrolled in an introductory mechanics course at the University of Bergen. Hierarchical Principle Structure for Mechanics (HPSM) was used as the intervention tool to implement retrieval practice. HPSM comprises all the essential principles and definitions relevant to the mechanics course under study. The first phase of the experiment was a memory test that explored if retrieval practice, using (HPSM), is more effective in improving students' basic factual knowledge than just studying problems. The results proved the effectiveness of retrieval practice by substantial effect size ($d = 1.42$). The second phase was a transfer test that entails incorporating retrieval practice into all the lectures to see if there is any correlation between students' frequency of attendance (i.e., amount of retrieval practice received) and scores for the basic knowledge test and the final exam tests for solving actual physics problems. The results showed that retrieval practice was correlated with both the factual test and the final exam (which had problem-solving questions, indicating transfer). Retrieval practice appeared to be particularly helpful for weaker students. Overall, the results suggest that practicing recalling different pieces of key physics knowledge was beneficial not just for subsequent recall but for transfer as well.

3. **Hardiman, P. T., Dufresne, R., & Mestre, J. P. (1989). The relation between problem categorization and problem solving among experts and novices. *Memory & Cognition*, 17(5), 627–638. <https://doi.org/10.3758/BF03197085>**

In a two-stage study, Hardiman, Dufresne, and Mestre (1989) established a significant correlation between the ability to categorize similar problems and solve them. In the first stage, experts and novices performed a similarity judgment task to ascertain which two physics problems would be solved in a similar manner. Their performance was studied to see if they employed surface features, deep structure, or both to categorize problems. In the second stage (problem-solving stage), only novices participated and the relationship between problem categorization and the ability to actually solve the questions were studied. The results reaffirmed that those who scored better on problem-solving relied more on the underlying principles of physics. Novices, on the other hand, mostly picked on surface information and got involved in the details pertaining to equations and formulae. The results revealed that categorization based on principles is highly correlated with problem-solving abilities. The relationship could be justified through the fact that it is more efficient and effortless to organize physics knowledge in terms of broader principles than maintaining and searching through an equation database. Hence, the study suggests that pedagogy in physics can be made more effective by organizing information based on principles.

4. **Zu, T., Munsell, J., & Rebello, N. S. (2019). Comparing retrieval-based practice and peer instruction in physics learning. *Physical Review Physics Education Research*, 15(1), 010105. <https://doi.org/10.1103/PhysRevPhysEducRes.15.010105>**

A comparison between retrieval-based practice and peer review reveals that while retrieval practice results in significantly better scores for the initial task and immediate far transfer tasks, there is no major difference in other scores. The study compares the two learning techniques to evaluate their respective effectiveness for problem-solving, retention, and transfer. It also aims to ascertain if there is any correlation between instructional practice and metacognitive performance. The study comprised 68 physics students who were divided into small groups for the experiment. First, all the students were shown two multimedia videos based on the subject (speed and conservation of energy). Each group was then randomly assigned to one of the instructional methods. For retrieval practice, the groups were shown an example problem, asked to retrieve the definition and application of the concept, and finally to solve the problem. The intervention was fundamentally re-testing of a similar question as taught in the instruction video. To ensure retrieval practice is effective for transfer, questions were designed not to just retrieve information but also to identify concepts and use them to solve questions. For the peer instruction condition, groups were presented with slides from the learning videos. Students then took turns explaining the slides to their fellows. The intervention was similar to restudying, except it happened in a group rather than individually. After each step, students filled out the judgment of learning surveys to rate their learning. The results showed that retrieval practice was better than peer instruction for delayed initial task score and immediate far transfer task score. But for the immediate initial task and immediate and delayed near transfer tasks, there was no significant difference. It was also found that the scores for

metacognitive judgment of learning were higher for peer instruction than for retrieval-based practice, which indicates that students are more confident in their learning with peer instruction

5. Schwartz, D. L., & Martin, T. (2004). Inventing to Prepare for Future Learning: The Hidden Efficiency of Encouraging Original Student Production in Statistics Instruction. *Cognition and Instruction*, 22(2), 129–184. https://doi.org/10.1207/s1532690xci2202_1

The paper focuses on how production activities, such as inventing to preparing for learning (IPL), can contribute to learning. It is an extension of several previous studies that demonstrated that scaffolding through discovery or invention does not yield improvement in students' achievement in the follow-up tests (Klahr & Nigam, 2004). It presents a detailed theoretical basis to explain why production activities should not be confused with learning as their purpose is mainly to prepare students to learn. Hence, they shouldn't be perceived as contradictory or an alternative to direct instruction. This means that the effectiveness of this instructional design cannot be measured via regular problem-solving assessments. Instead, specific assessments to measure *preparation for learning* are needed to evaluate the effectiveness of this strategy. One of the characteristics of discovery/productive failure/IPL is that it usually requires a complete cycle that consists of discovery, feedback, instruction, practice, and finally assessment. If any of these components are left aside, the learning technique might not produce desired results, especially in assessment. This is because it is meant to target long-term transfer and learning, along with the immediate transfer. IPL uses a double transfer paradigm in which a topic is studied using two different learning strategies, followed by a common learning opportunity such as direct instruction, and then a final transfer problem. This is a better approach to measure preparation for learning because it involves both 'transfer in' and 'transfer out'. The study employed a pre-test post-test design with 95 ninth-grade students. After the pre-test, all the students received IPL training that included three invention activities, a lecture, and practice. Then the participants were randomly assigned to the invention (solving novel problems) and tell-and-practice group (studying solved problems). In the post-test, the students were further divided into those who received study material in the test and those who did not. This created a 2 x 2 x 2 design of instructional treatment x presence/absence of resource in posttest x pre-test/posttest performance on the transfer problem. It was hypothesized that the invention plus common learning resource would yield the best result in the transfer test as compared to 1) only invention then test 2) only tell-and-practice then test 3) tell-and-practice plus common learning and then test. The hypothesis was proven right with results showing that the invention group clearly outperformed the tell-and-practice group, with a significant interaction between instructional method, availability of the resource in the exam, and pre to post-test gain, $F(1, 91) = 4.9$, $MSE = 0.40$.

6. Gjerde, V., Holst, B., & Kolstø, S. D. (2021). Integrating effective learning strategies in basic physics lectures: A thematic analysis. *Physical Review Physics Education Research*, 17(1), 010124. <https://doi.org/10.1103/PhysRevPhysEducRes.17.010124>

The paper identifies that there is a wide gap in research when it comes to the integration of learning strategies into physics education. Therefore, it aims to implement three established learning strategies into mechanics teaching and acquaint students with them. These three strategies are retrieval learning, elaborative encoding, and self-explanation, and they were used along with their respective scaffolding techniques. The efficacy of these techniques is well-established already, and the paper explores more meaningful ways of implementation. Elaborative encoding refers to making deliberate connections between units of knowledge so that they become easier to remember. Retrieval practice refers to purposefully retrieving from memory to improve its retention. Self-explanation means to elaborate on each step of a solved problem and explain why it is done the way it is done. The intervention of introducing different learning strategies was practiced with 150 physics students. The three strategies were incorporated into regular lectures and problem-solving seminars. Students were first introduced to the three techniques by explaining how and when they should be used. They implemented elaborative encoding and retrieval practice in the first 15 minutes of one of their two lectures every week. Self-explanation was implemented by providing students with detailed solutions to the previously received questions. Students had to explain each step in the provided worksheets. Data was collected using student interviews in which specific questions were asked to probe students' experiences and reflections about different learning techniques. While for many students encoding and retrieval practice helped with the retention of the core concept and they continued using it even outside the study, many found it boring like rote learning. With self-explanation, most students did not recognize it as a learning strategy. They lacked the metacognitive skills to use self-explanation when solving problems and therefore, retrieved to their own conventional techniques. A consistent problem with implementing these strategies is students being impatient with setting up the problem and jumping into solving it.