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Embedding Better Learning: Retrieval Practice in an Embedded Systems Course

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Embedding Better Learning: Retrieval Practice in an Embedded Systems Course

Abstract

Retrieval practice, the active recall of previously learned information, has been widely documented in educational research to enhance long-term student learning more effectively than alternative study strategies. This strategy has been shown to be effective even with complex materials. Despite the supporting research, there is a relatively small volume of literature about the application of intentional retrieval practice in engineering education.

In this work, a junior-level embedded systems course was redesigned to incorporate retrieval practice in many formats, including use of white boards, retrieval trivia, brain dumps, and mastery-based quizzes in hopes of improving student learning. Recognizing that small sample sizes limit the measurement of student learning gains, this study is designed to address two key research questions about the introduction of retrieval practice in this course:

- RQ1: Do students understand how to apply retrieval practice?
- RQ2: Do students see value in using retrieval practice to study?

This paper reports on the change in perception across the semester for electrical and computer engineering students encountering intentional retrieval practice for the first time in an engineering class.

Introduction

Retrieval practice, which is the act of freely recalling previously learned information without the aid of notes to promote learning, has consistently been demonstrated to improve long-term learning. This has been shown in a variety of content areas and educational settings to improve learning to a greater extent than time spent on other classroom activities such as reviewing materials, rereading notes, or lectures without retrieval practice. As a result of these improvements to student learning, educational researchers recommend scheduling retrieval interventions regularly [1, 2].

Retrieval interventions rely on the "testing effect", which is the fact that students will retain and remember materials better in the future if they are tested on material and successfully recall the content. Studies have shown that being tested on material shortly after learning it is more effective than rereading or reviewing materials for long-term recall [3, 4, 5]. This effect has been found to hold for complex material as well, which is promising for application in engineering classrooms [6].

Several particular retrieval interventions have been studied extensively, and lend themselves well to an engineering education context. One such intervention is spaced retrieval practice. Spaced retrieval practice is the approach of asking students to recall the same information over a long time frame. This practice is in contrast to massed retrieval, where the opportunities to recall information are provided in a single, limited time span [7, 8]. One example of spaced retrieval practice is asking students to answer several questions on the same topic across several quizzes across several weeks (spaced) versus asking the same questions on a single quiz or exam (massed) [2]. Spacing has been shown to improve knowledge retention over massed retrieval [2, 9, 10].

Another retrieval practice intervention with promise for an engineering context is interleaving, or mixing multiple retrieval topics together in the same assignment as an alternative to blocked practice, in which all assignment questions of the same type are presented together [11]. Blocked practice is typical in mathematics courses in which students are introduced to a particular strategy and then given practice problems which require use of that strategy [12]. Interleaving practice has been shown to help students retain content knowledge, and has even been adopted into popular language learning apps [12, 13].

The retrieval practice intervention most relevant to the work presented in this paper is the application of low-stakes quizzing, which relies on the testing effect. Research has shown that low-stakes quizzing improves student learning over typical instruction and rereading content. These benefits persisted through end-of-semester assessments, and the most effective strategy has been found to be spaced, low-stakes quizzing with immediate feedback [14, 15, 16].

Although retrieval practice has long been studied by cognitive psychologists, the direct application of this practice has only been widely adopted for the past two decades [1, 3]. As a result, there are relatively few examples of retrieval practice used in engineering contexts. Most examples have been used in engineering mathematics or K-12 STEM settings [2, 9, 10, 12, 17]. The most prominent example of retrieval practice applied in an engineering context is an application in a thermodynamics course [7].

This study aims to add to the literature on the intentional use of retrieval practice by investigating the perception of engineering students about retrieval. This study is the first step in a longer investigation of student learning gains, focused on whether or not students believe they understand what retrieval practice is and how it benefits their learning. The study is aimed to answer the following research questions:

- RQ1: Do students understand how to apply retrieval practice?
- RQ2: Do students see value in using retrieval practice to study?

Course Information

The retrieval practice interventions described in this work were applied in ECCS 3351: Embedded Real-Time Applications, which is required for all electrical engineering and computer engineering students at Ohio Northern University. This course falls in the third year, fall semester in the plan of study for the typical student. The course may also be used as an elective by students in mechanical engineering or computer science, and is included as an option for the Robotics concentration in all four majors. The course covers standard embedded systems content with a focus on mobile robotics, and employs the Texas Instruments Robotics System Learning Kit with a TI MSP432 LaunchPad with an ARM Cortex™-M Processor, and accompanying textbook [18]. This course was chosen for three reasons. The first is that it is a required course for ECE students. The second is that a recent redesign to the course has shifted the course to a mastery-based learning approach. In mastery-based learning, students demonstrate mastery of required skills primarily through low-stakes quizzes that can be repeated after failure [19]. The application of low-stakes quizzing is a form of retrieval practice. Finally, this course was chosen because embedded systems content requires recall/memorization in order to interpret datasheets, write functions, and recall which registers are important. There are limited numerical calculations as in other upper-level engineering courses, which lends well to helping students understand the value of retrieval practice.

Retrieval Strategies

A variety of retrieval practice interventions have been studied, with spaced, low stakes quizzing showing the most promise. However, all types of retrieval practice have been shown to provide some benefit over typical course structures [1]. This section outlines several retrieval practice strategies applied in the ECCS 3351 course.

White Boards

The most commonly applied strategy for implementing retrieval practice in this course was the use of hand-held individual white boards with dry-erase markers to allow students to retrieve information. These white boards were typically used for review using retrieval at the beginning of lecture, and for ‘rapid retrieval’, in which students are asked a quick, low stakes question about content they have previously covered every few minutes during lecture. This strategy is helpful, not just for students to gain quick feedback on what they remember, but also for instructors to discern what percentage of the class understands and remembers the course material. To remember to use rapid retrieval, a photo of a retriever (dog) every few slides can be helpful. Whiteboards are also used for students to make drawings, ‘brain dump’ everything they can remember on a topic, or provide questions for the faculty [15]. One prompt that was very useful in this course was “what was most difficult to understand about today’s lecture?”, which gives students time to reflect and recall what they have learned. Figure 1 provides an example of a slide used to remind faculty and students that it is time for retrieval. The question posed is typically associated with the slide in question and ties the content on the slide to previously covered material. The particular prompt for this slide was “what is the difference between && and & in C99?”.

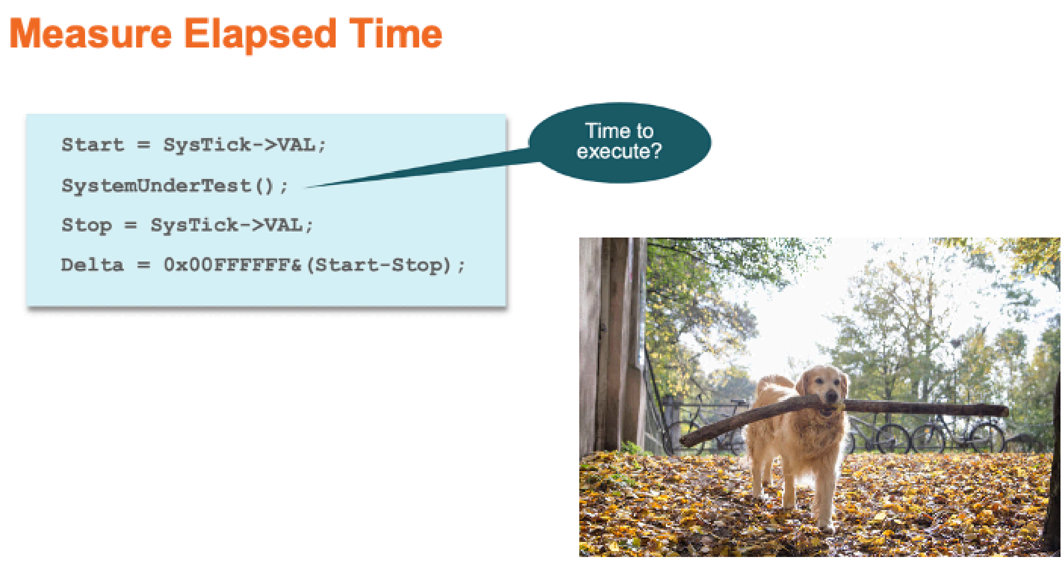

Figure 1: Example slide used to prompt use of retrieval practice

Retrieval Trivia

For content that required memorization, trivia was used to provide students an opportunity to review for quizzes with retrieval. Teams of 3-4 students were formed, and groups were not allowed to access notes or other resources to answer questions. Each question had a 30-60 second time limit. This activity allowed students to practice retrieval and engage in short bursts of peer-teaching as team members convinced their peers of the correct answer [20]. Particular trivia topics included instruction set and data acquisition.

Mastery Based Quizzing

One of the most significant applications of retrieval practice in the course leverages the testing effect is the application of a mastery-based learning approach with quizzes that can be repeated until students demonstrate mastery [19]. The application of low-stakes quizzes directly leverages retrieval practice through the testing effect, but also allows students to use spaced retrieval practice and interleaving [2, 4, 6, 11].

In this course, the majority of the assessment was tied to performance on mastery quizzes. Tested skills are shown in Table 1. Skills with an ‘R’ were required to pass the course, while ‘P’ and ‘A’ level skills could be accumulated for students to improve their overall grade in the course. Each quiz was designed to teach one well-defined skill. New quizzes were introduced on Fridays, based on the week’s content. If a student was unsuccessful on the first attempt, a similar quiz with different questions was available in subsequent weeks, giving students a chance to use spaced retrieval practice. Quizzes were, in general, returned in the following class meeting to provide very quick feedback. Students were allowed to test up to 3 skills per quizzing opportunity, and since each skill was distinct, this was a form of interleaving. More detail on the mastery-based framework can be found in literature [19, 21].

Table 1: Tested skills in mastery-based framework embedded systems course

Skill	
R1	Demonstrate ability to specify registers and memory addresses
R2	Demonstrate the ability to write C code for embedded applications
R3	Configure and use ports for input and output
R4	Control DC motors
R5	Demonstrate principles of embedded system communication using UART
P1	Use timers to measure time
P2	Acquire and process data on an embedded system
P3	Design software using a structured Finite State Machine
A1	Implement interrupts in embedded systems
A2	Implement PWM on embedded systems
A3	Implement feedback control with PID
A4	Demonstrate basic principles of robot odometry
A5	Demonstrate principles of embedded system communication using SPI
A6	Demonstrate principles of embedded system communication using I2C

Assessment

In order to evaluate the research questions:

- RQ1: Do students understand how to apply retrieval practice?
- RQ2: Do students see value in using retrieval practice to study?

students were given a short 5 question survey both at the beginning of the semester and at the end of the semester. Students were asked to rate their agreement with the following prompts on a 5 point Likert scale, with 1 being Strongly Disagree and and 5 being Strongly Agree. Table 2 shows the prompts.

Results

For both the pre- and post-course surveys, 29 out of 38 total students in the course responded to the survey. Figure 2 shows the percentage of respondents who agreed or strongly agreed with the survey prompts for the pre- and post-course surveys. Table 3 shows the results numerically.

Table 2: Prompts for pre- and post-course survey

RQ	Prompt
1	I know what retrieval practice is
1	I can apply retrieval practice to my study habits
2	I believe I learn better using retrieval practice than rereading class notes
2	Retrieval practice helps me connect concepts
2	I would recommend retrieval practice to a friend

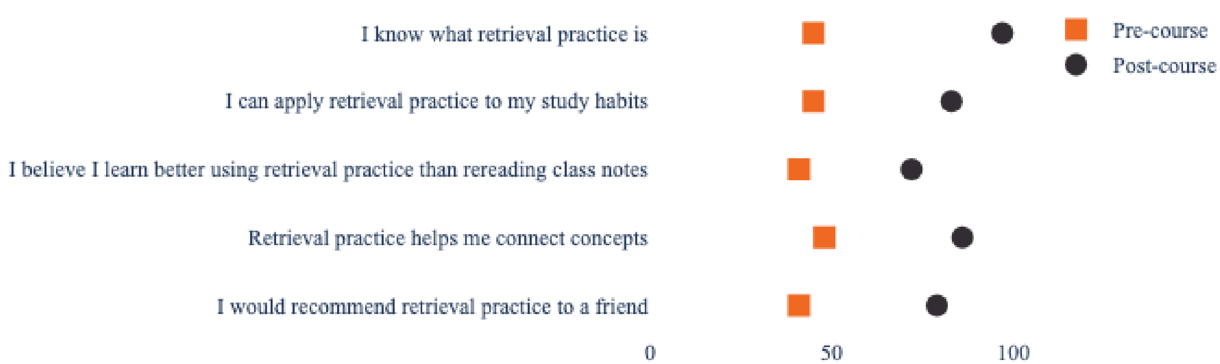

Figure 2: Percentage agree or strongly agree for pre- and post-course survey for prompts

Table 3: Percentage agree or strongly agree for pre- and post-survey

RQ	Prompt	Pre-Course Survey	Post-Course Survey	Change
1	I know what retrieval practice is	45%	97%	+52%
1	I can apply retrieval practice to my study habits	45%	83%	+38%
2	I believe I learn better using retrieval practice than rereading class notes	41%	72%	+31%
2	Retrieval practice helps me connect concepts	48%	86%	+38%
2	I would recommend retrieval practice to a friend	41%	79%	+38%

For all prompts, there was an increase of at least 31% of respondents who agreed or strongly agreed. For RQ1, an average of 45% more students agreed or strongly agreed with the prompts after completing the course. This suggests that the course was very effective in helping students understand how to apply retrieval practice. For RQ2, an average of about 36% more students agreed or strongly agreed with the prompts after completing the course. Again, this suggests that by completing the course and the retrieval practice interventions, more students came to see this as valuable. One particularly compelling measure of value is "I would recommend retrieval practice to a friend", which 79% of respondents agreed or strongly agreed with after the completion of the course. If someone sees value in something, they can't help but share [22]. These results suggest that engineering student perception of retrieval practice increased as a result of a single course, and that students both believe that they understand how to apply retrieval and find it valuable.

Discussion

This study provided encouraging results for improving student perception and feelings about the use of retrieval practice as a strategy for studying and learning. Further work is needed to determine if students actually do understand what retrieval practice is and are able to independently apply these strategies. Also, future work would be required to determine the actual effectiveness of retrieval practice in upper-level or downstream engineering courses.

Several students commented on the use of retrieval in course evaluations as strengths of the course. Of 36 respondents on the course evaluation, 33% (12) students directly called out the ability to retake quizzes as a strength, and 4 directly referenced retrieval practice as a strength. One student stated that they "*liked being able to retake quizzes since it made me actually learn the material*" while another commented that they "*really thought the ability to retake quizzes until we passed was a great idea. It really helped retain the info better.*" Still others commented that *"using the whiteboards to ask us important questions was also helpful*" and they "*enjoyed the lectures and using the whiteboards.*" Most encouraging was a comment that one student *"greatly enjoyed the retrieval practice elements of the course, I found them to be very useful when memorizing information."*

This response was not uniform, as some students did not like the memorization aspect of the course. One student felt that "*there was too much focus on short-term memorization for the quizzes. I feel like I memorized a lot but learned very little and will not retain most of what was covered.*" Another student commented that a weakness of the course was "*most of the needing to memorize code for quizzes and such, in the real world there is absolutely no need to memorize the code*." The last comment brings to light the inertia that educators must overcome with students who don't believe there is anything that they should 'know', since they feel they can look it up. While only a single student voiced this comment, it more broadly reflects the fact that not everyone sees the benefit of interventions that are intended to be helpful for student learning, knowing, and remembering. So, while most students who participated in this study both understood how to apply retrieval practice and saw its value, there is still work to be done to encourage wide adoption in engineering student study habits, and to help students see the value of knowing and remembering.

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