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Incorporating Evidence-based Teaching Practices in an Engineering Course to Improve Learning

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Abstract

The most important goal of teaching is student learning, passing on information from the instructor to the student so they can apply those concepts and skills months and years after instruction. However, this goal is not easily accomplished. Thinking and learning take significant effort and students often resist putting in the required work. Additionally, the increasingly diverse student population and recent disruptions to traditional classroom learning require instructional design to meet learning outcomes. Three evidence-based teaching practices including retrieval practice, spaced (distributed) practice, and interleaving were incorporated into a hydraulics course to improve student learning and evaluated for their effectiveness. This paper describes the practices, how they were employed within an engineering course, and evaluates their success using data as available and student feedback. Of the three practices, students indicated retrieval practice as the most effective as 89% of respondents used classroom retrieval practices to adjust their study and preparation for tests and 67% thought retrieval practice would help them remember concepts past this course. Quantitative support of student learning (in the form of test grades) was not significant. Spaced practice outperformed student expectations and was perceived as helpful for chapter test preparation while interleaving was moderately incorporated into the course with low perceived impact.

Introduction

Learning is at the center of every classroom. It is the process of acquiring new information or understanding, storing it, and later retrieving it for application in a process often called "transfer" [1]. In the classroom, this is seen as the passing of information from instructor to student. This information is held for short periods of time and processed in the working memory space of our brains; it can be manipulated through thinking [1], [2]. Each distinct piece of information is considered an element or "chunk," and our working memory can only hold four to seven elements at a time [1], [2]. Unlike working memory, however, long-term memory is nearly infinite with information linked together through memory schemas. A schema is a set of elements categorized according to their potential application [1]. A single schema can combine many pieces of information that are processed as a single element or "chunk." By chunking material and building schemas the cognitive load on working memory can be reduced. Therefore, generating an increasing number of ever more complex schemas by combining elements of lower-level schemas into higher-levels schemas creates expertise and the skills required for engineering [1], [2]. A meaningful engineering education must include moving learned concepts and ideas from working memory to long-term memory, encoding them as complex schemas for storage, and then being able to retrieve or recall them when needed [2].

Extensive research has demonstrated the effectiveness of various teaching practices for improved learning and explained them using educational theory of constructing complex schema. However, engineering instructors are typically not trained educators and often have limited experience with education theories. This has resulted in engineering education lagging other science education in its employment of learning theory [3]. Evidence suggests that this lag in best educational practices causes students to drop out of STEM, causing pipeline problems for STEM occupations [4]. Being aware of this, engineering education scholars have called for more explicit use of theory in educational research, yet there are few detailed discussions in the engineering education literature about what theory means and how it is best applied in engineering education [3].

Dunlosky et al. described and evaluated ten effective learning techniques based on cognitive psychology including retrieval practice, spaced (distributed) practice, and interleaving, yet none applied specifically to engineering courses [5]. These three evidence-based teaching practices were incorporated into a hydraulics engineering course to improve student learning and evaluated for their effectiveness. This paper describes the teaching practices, the application of them into an engineering course, and the assessment of their effectiveness.

Background: three evidence-based teaching practices

Retrieval practice

More than one hundred years of research and hundreds of experiments have demonstrated that practice testing enhances learning and retention [5]. Practicing retrieval improves the ability to retrieve it again and promotes meaningful, long-term learning where recall of complex schemas becomes automated [1], [2], [6]. Practice testing requires a search of long-term memory that activates related information which then is encoded along with the retrieved target forming additional schemas to facilitate later access to that information. Practice facilitates the encoding, enhances how well students mentally organize information, and supports better retention and criterion test performance [5]. Studies show that students who have been tested between the initial learning and the final test outperform students only given the final test, including in engineering math [7], [8].

Practice testing has broad applicability. The format of the practice test does not need to match the format of the criterion test and has been demonstrated to be effective when the criterion test requires inferences or the application of previously learned information. Testing a subset of related information also improves memory of related but untested information [5].

Practice testing is a low- or no-stakes practice that could be guided by the instructor or student with little instructor time [5]. For example, a student could practice by recalling definitions, solving additional problems, or taking a practice test provided through a digital textbook. A practice test could also be administered by the instructor during class. Whether student-initiated or instructor design, more practice tests are better than fewer and increased spacing between practices is better [5]. In whatever format retrieval practice is implemented, it is a no-cost intervention with high impact [8].

Distributed (spaced) practice

Distributed (spaced) practice spreads out opportunities for memory storage and retrieval of taught information to develop complex schema that improves long-term retention as compared to last-minute "cramming" or massed practice [2], [9]. After a topic is introduced, forgetting begins and continues to decline [9]. Think back to this morning, what did you eat for breakfast? Can you recall what you ate last Thursday? Probably not. However, if you came across the detailed receipt for your breakfast, you would probably remember and picture the food before you ate it. This stimulus breaks up your forgetting pattern and improves your learning. Distributed practice does the same thing for learners as the receipt does for you.

Students engage with material, forget it, and then engage with it again when reminded. These reminders could be a lecture that repeats information read in the textbook, a homework problem to apply the material, or even a quiz for recall [9]. All reminders break the forgetting pattern, but the more you interrupt it with practice retrieving memory from schemas, the more likely that the next recall attempt will be successful [2]. Distributed practice is closely related to retrieval practice in that a quiz for retrieval practice provides a stimulus to think about and recall something which also interrupts the forgetting pattern.

While more practice is better, general suggestions for ideal spacing and practice content are demonstrated through research. Optimal learning is achieved when teaching is balanced with the cost of forgetting. Too much forgetting leads to the inability to be reminded well, but too little forgetting leads to pointless reminding. The optimal time is not specific, but it should be long enough so that it requires effort to remember. That thinking effort will make it easier to recall in future sessions or on a criterion test [10]. Additionally, the practice must have enough similarity to instruction to elicit reminding, but not too much that recall is obvious [9].

Interleaved practice

In many engineering courses, the instructor uses a textbook divided into chapters that are assessed with tests. A common structure includes the use of blocked practice where students are assigned several homework problems each day, week, or chapter, before moving on to the next chapter and subsequent tests. This sets up students for success with their homework because they may rely on their working memory, and they know where to find applicable equations and theory in the textbook. However, it may not support their long-term success when information taught at the beginning of the semester is required for subsequent chapters within that course, subsequent courses, the fundamentals of engineering exam, or a future career. Interleaved practice has been demonstrated to improve student learning and retention of technical skills, though the literature on this practice is smaller than others [5].

Interleaved practice involves practicing already-learned material along with newly learned material. When all homework or quiz problems are bunched together, students expect that every problem must be a variant of the skill they are practicing. However, when homework or quiz problems draw from mixed material, students practice thinking through which solution methods to use and how to apply what they know [5], [11]. Dunlosky et al. cites trials from Rohrer and Taylor (2007, 2010) that compared student performance during practice with testing. Students participating in blocked practice had better practice performance, but those participating in interleaved practice had better test performance in both trials. Interleaved practice helps students discriminate between various kinds of problems and learn the appropriate method for each one. It requires that students organize tasks and solution methods. Therefore, during interleaved practice students are practicing two things: the skill being taught as well as the skill of identifying which solution method should be used [5]. Interleaved practice naturally covaries with distributed practice. Therefore, some of the benefits of interleaved practice may reflect the benefits of distributed practice, such as practice pulling from long-term memory to form schemas [5].

There is little guidance in the literature on how much initial instruction to provide before interleaved practice commences, but there is at least partial support for the hypothesis that interleaved practice may be most beneficial only after a certain level of competency has been achieved using blocked practice. Dunlosky et al. provides a guide for implementation: After initial instruction of a certain kind of problem, that problem should be practiced and then followed by additional practice that involves interleaving the current type of problem with those introduced during previous sessions [5]. The Department of Psychology at the University of California, San Diego, suggests a practice where 75% of your study time could be dedicated to learning new materials and 25% to reviewing old materials [12]. Thus, interleaving is also an application of distributed practice as each review of old material acts to interrupt the forgetting curve as described above. One potential concern could be the increased time required to complete practice sessions as students also spend time determining which solutions methods to employ [5].

Application: practices applied in an engineering course

Course description

Hydraulic Engineering is a four semester-hour course taught primarily to upper-level civil and environmental engineering students. It applies the basic principles of fluid mechanics to practical problems in hydraulic and hydrologic analysis. Topics include fluid flow, hydrostatics forces, pressurized pipe flow, water distribution, open channel flow, hydrology, surface runoff, rainfall, and risk. Computer modeling and laboratory exercises are used to emphasize principles. The course meets three days a week for 65 minutes each session. Several lab activities are used as in-class activities while others that require more intensive calculations and reporting are assigned outside of class. Additional course components include homework problems, a research presentation, and unit tests.

Adjustments were made to the schedule and assignments to improve student learning and incorporate three teaching practices as described below. Throughout the course planning, care was taken to rearrange the student workload, not increase it. Table 1 shows a comparison of the number of homework and lab activity questions over four grading arrangements of the course. A notable change occurred in 2020 when a new instructor was hired to teach this course who began distributed practice (discussed below). Several complex, open-ended, or modeling problems were moved from large homework sets to lab activities between 2020 and 2022. Only one additional problem was added between 2022 and 2023 when interleaving was included in the course design.

Table 1. Number of questions assigned for each topic (T#) on each homework (HW) or lab activity (LA) along with longitudinal comparison of total problems per assignment per year. Prior to 2020, several topics were grouped together according to tests. Asterisks indicate where additional questions could be inserted for more complete interleaving.

	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**2023**	**2022**	**BEFORE 2020**
LA1	2										2	2	
HW1	9										9	12	16
LA2		2									2	1	
HW2	2	5									7	6	
HW3	2	2	6								10	8	23
HW4	0.5		0.5	3							4	5	
LA3			1	3	1						5	5	
HW5		1	0.5		3.5						5	3	
LA4						4					4	6	
HW6	2					6					8	6	
HW7				*			6				6	8	9
LA5						1					1	1	
LA6							3				3	3	4
LA7								2			2	2	
HW8			*					5			5	7	18
HW9				*					10		10	7	14
LA8									3		3	3	3
HW10	2	1				1				3	7	7	
LA9			1					1	1	*	3	3	
SUM	19.5	11	9	6	4.5	12	9	8	14	3	96	95	87

Retrieval practice

Retrieval practice was incorporated into this class through frequent, short quizzes to recall facts, concepts, or events from memory. One to two days a week, class began with a short quiz comprised of 1-6 questions. The questions were printed on paper and handed out as students entered class. After five to ten minutes, solutions were projected using the lecture slides while students switched writing tools and self-graded their quizzes. Several example retrieval practice quizzes are included in the appendix. Usually, quizzes were completed individually, but sometimes they were completed with a partner to encourage community or shared learning. The level of difficulty varied depending on the goal and timing within the semester. Sometimes these practices were easier, reviewing past information and sometimes they were harder to prepare students for an upcoming test. Retrieval practice quizzes included questions on assigned reading, previous lecture content, and homework. This encouraged students to keep pace with reading sections and homework assignments in case that content was included in the quiz. No make-up quizzes were given if students missed class or arrived late. However, the lowest 10% of quiz grades were dropped at the end of the semester. This encouraged students to attend class and arrive on time to have the opportunity to take the quiz while still giving them flexibility to miss class when needed without a grade penalty.

Distributed (spaced) practice

Distributed practice was applied to this course in several ways. Prior to 2020, this course was structured by two tests, two labs, and a final exam. At each test, a large homework packet was due and graded mostly on completion. This left students to determine when they would complete the problems – shortly after the material was covered in class or right before the test when it was due. The course was rearranged to discourage this last-minute test cramming and encourage at least some amount distributed practice by increasing the frequency of homework sets and tests. As seen in Table 1, ten homework sets were spread out over time and due weekly to prevent delaying work until just before a test. Unit tests were provided with increased frequency. Studying for a test is another stimulus to increase learning. Daily reading sections were assigned to keep pace with lecture content. (Accountability for reading was provided through retrieval practice as previously described.) Therefore, students engaged with content at least three times each week in addition to test preparation. These occurrences served as reminders that interrupted the forgetting pattern. Additional reminders were provided through retrieval practice quizzes and lab activities spaced throughout the semester. Spaced practice works best when there is a break between practices which aligns well with a M W F meeting schedule. An additional benefit to frequent testing included allowing each test to cover less content and contribute less to the overall course grade, reducing stress for students.

Interleaved practice

Interleaving was included in this course through the arrangement of homework sets, lab activities, and frequent retrieval practice quizzes that included problems from recent and past course content, as seen in Table 1. For example, after topic #2 was introduced and practiced in class, homework set #2 was assigned. Homework set #2 provided five questions related to topic #2 as well as two questions drawing from topic #1. Similarly, lab activity #3 was assigned during instruction on topic #5 but required application from topics #3, #4, and #5. Homework set #2 and lab activity #3, along with several other examples are included in the appendix. This process continued for most assignments. Lab activities #5-7 required large lab equipment and were single-topic focused with no opportunity for interleaving. Homework sets #7-9 also lacked interleaving, but this was accidental and not an intentional instructional design. Asterisks in Table 1 indicate where additional questions could be added (or rearranged) to provide improved interleaving. The total number of questions associated with each topic should correlate to the lecture time and/or level of importance of the topic. From this table, it appears that topic #1 was over practiced.

Interleaving did not require a large increase in homework questions. Instead, previously assigned problems were rearranged and only one question was added for interleaving, as seen in Table 1. For example, the 2022 homework set #1 included twelve problems. Three of those problems were removed and relocated to other homework sets or activities. Some problems were just repeated using different values. The 2020 version of homework set #3, #4, and #5 totaled twenty-three questions whereas the 2022 version included only fourteen from that topic. Five of those questions formed lab #3 in 2022. The remaining questions were either removed from the course or interleaved through other assignments.

Student and Course Assessment

Success of the course instruction and evidence-based teaching practices was assessed by student semester grades and their perceptions of the practices. Student course grades were weighted according to Table 2. Of these grades, teaching practices were incorporated into homework, retrieval practice, labs, and tests/exams. Using four years of data, student semester average retrieval practice and homework grades were compared to average test grades as indicators for expected course success. Student perceptions of the practices were assessed through a pre- and post-semester survey. The pre-semester survey asked students how familiar they were with the various practices (interleaving, spaced practice, retrieval practice) and how well they thought the practices would help prepare them for chapter tests, the final exam, and long-term retention of material after the course. After the semester, students were asked how well they thought the practices helped them prepare for tests, exams, and long-term retention. For each survey, students responded to the questions using a five-point scale where five represented high familiarity, expectation of preparation, or experienced help in preparation. The post-survey also included free response questions about their experiences, specifically related to retrieval practice. A list of survey questions is included in the appendix.

Table 2. Grade allocation for engineering course

ASSESSMENT	**GRADE (%)**
Homework Assignments	10
Labs/In-class Activities	20
Research Presentations	5
Retrieval Practice	5
Chapter tests (40%) / final exam (20%)	60
Total	100

Results

Four years of student test grades were analyzed for changes and trends correlated to evidence-based teaching practices. In 2020, the first year analyzed, no evidence-based teaching practices were included in the course. In 2021-22, spaced practice was included through homework and limited retrieval practices were provided. All three practices were incorporated into the course in 2023. No longitudinal changes in test scores were noticeable over the years, nor did homework or retrieval practice scores correlate to test scores during any given semester.

This engineering course is small with only fifteen students; however, the survey participation was high and reflective of the full diversity of the class. Ninety-three percent of students responded to the first survey while 60% of students responded to the end-of-semester survey. Table 3 displays student responses.

Table 3. Average student survey responses regarding familiarity and expectations or experience with evidence-based learning practices.

Pre-semester questions	**Average Score (from 1 to 5, with 5 being most familiar/highest expectations)**		
	Interleaving	**Spaced Practice**	**Retrieval Practice**
How familiar are you with this practice?	2.8	3.3	3.8
How well do you think it **will help** you prepare for the unit tests?	4.0	4.0	3.7
How well do you think it **will help** you prepare for the final exam?	4.2	3.7	3.8
How well do you think it **will help** you remember concepts past this course?	3.8	3.9	3.8
Post-semester questions	**Average Score (from 1 to 5, with 5 being most familiar/highest expectations)**		
How familiar are you with this practice (after the semester)?	3.8	4.4	4.7
How well do you think it **helped** you prepare for the unit tests?	4.0	4.3	4.7
How well do you think it **helped** you prepare for the final exam?	3.7	3.9	4.0
How well do you think it **helped** you remember concepts past this course?	3.3	4.1	4.6

Students were asked to describe their experiences with the three practices and retrieval practice specifically. Meaningful student quotes and anecdotes are included in the discussion. Several students described how retrieval practice altered the way they prepared for the test. They indicated that retrieval practices showed them what they really knew versus what they thought they knew and 67% changed the way they studied or prepared for tests as a result. After reviewing these survey results, student test grades were compared to homework and retrieval practice grades. Table 4 displays the percentage of student grades on tests that were higher than, equal to, and lower than homework and retrieval practice grades. Students were also asked about increased stress and anxiety caused by retrieval practices. Twenty-two percent of survey respondents said their grades on the retrieval practices increased their stress or anxiety over the semester.

Table 4. The percentage of students with test letter grades higher than, equal to, or lower than homework (HW) and retrieval practice (RP) grades where grades were defined by a typical grading scale (80-82=B-, 83-86=B, 87-89=B+, and so on)

	2020	2021	2022	2023	AVERAGE
TEST > HW	33%	0%	7%	13%	13%
TEST = HW	42%	64%	36%	31%	43%
TEST < HW	25%	36%	57%	56%	44%
TEST > RP		18%	36%	60%	38%
TEST = RP		64%	29%	27%	40%
TEST < RP		18%	36%	13%	22%

Discussion

This hydraulic engineering course went through several modifications between 2020-2023. A new instructor began teaching it in the fall of 2020. As with every instructor change, time is required to become familiar with the course content and develop effective teaching pedagogy. However, that was not the only substantial change that occurred in 2020. Global disruptions due to the COVID pandemic in 2020 impacted classroom setting, teaching habits, and students' high school education. The pedagogy employed in fall 2020 was geared toward a hybrid model where some students were in-seat while others were online. This required content delivery to be digital with no use of classroom space or boards and group activities were discouraged due to social distancing requirements. The following year, some normalcy returned to teaching, but different strategies could be used with fully in-seat instruction. In 2023, the course meeting pattern also changed from meeting four sessions a week to meeting for three, longer sessions. Despite this pattern change, by fall 2023, life and teaching seemed normal, but the students in the classroom had their high school education interrupted resulting in variable retention and preparation for advanced engineering material. Additionally, this course is taught to a small number of students with the class size ranging from 7-15. Due to this variability, comparing test scores over the years had little value and could not be correlated to a specific teaching practice. However, comparison of homework and retrieval practice to test grades within each year as well as student free responses proved interesting. Student responses for each practice and key findings are discussed in the next section.

Retrieval practice

Students began the semester with the most familiarity of retrieval practice and indicated that it surpassed their expectations for learning, making retrieval practice the most effective of the three evidence-based practices. In fact, on the university-administered course evaluation, when asked, "What aspects of this course most helped your learning?" a student responded, "retrieval practices." Seventy-eight percent of survey respondents indicated that retrieval practice had a high impact on their success on chapter tests. They shared three main reasons for valuing this practice. Retrieval practice quizzes motivated better study habits, provided a realistic metric of mastery, and helped them prepare for tests.

Retrieval practice motivated students to develop better study habits during the semester.

- "It would make me look over my notes before every class" (student 6).
- "Retrieval practices helped outline what material I needed to study more and what types of things from each lecture might be a point of emphasis moving forward" (student 4).

Developing better study habits is a positive outcome from frequent retrieval practices, if there are no negative consequences associated with them.

One concern with retrieval practice is that it could increase student stress and anxiety. For unprepared students, the idea of having daily graded quizzes is stressful, especially when they continually perform poorly on them. Instead of encouraging students to review their notes daily in preparation for the quizzes, they could be a negative semester experience. In the survey, a student reported that quizzes "didn't increase my stress or anxiety because you emphasized how little impact on our final grade it has" (student 3). Another student shared, "even though they were graded, they didn't have a large impact on my final grade, which allowed me to relax and show what I knew each time we did a retrieval practice" (student 4). However, some students still experienced increased stress. "It was helpful to see what I was struggling in, but it did lower my grade and it made me a little more stressed" (student 5). "Although it was emphasized that the retrieval practice is not a large portion of the final grade, I still found myself stressed to get a good grade" (student 1). Overall, 22% of respondents said their grades on the retrieval practice quizzes increased their stress, even though they knew the retrieval practice grades would not greatly impact their overall course grade.

Retrieval practices provided realistic assessment. They provided timely feedback and highlighted what students *actually* knew versus what they *thought* they knew.

- "Knowing what I did or didn't know prior to the test was helpful for directing my studying" (student 7).
- "It was helpful to see what I was struggling in" (student 5)
- "It showed me when I knew or didn't know what was going on" (student 8)
- "It did help prepare me for tests because it helped me realize what I knew and what I needed to refresh" (student 3).

As engineers, if we want to know if a product or process is working, we must test it. It is no different if the "process" is learning. Frequent feedback is the only way to measure progress. Success on homework or retrieval practice may suggest to a student that they have mastery of a topic. As seen in Table 4, 25-57% of students scored higher on homework than on tests. If students used homework as a metric for mastery, their grades may give them a false confidence where they think they know more than they do. Additionally, homework is often due near the testing date, so if grades were low, there may be little time to react to homework scores and change study habits. In contrast, only 13-36% of students scored higher on retrieval practices than on tests so fewer students would have held that false confidence. In fact, 18-60% of students received a lower grade on retrieval practice than they earned on tests. Retrieval practice opportunities were frequent and spaced so students could adjust their study habits or focus study in the most critical directions in response to the grades before taking the high-stakes chapter tests. The retrieval practices served as formative assessments, focusing on improving the student's performance [5].

Retrieval practices helped students prepare for tests. They communicated what the instructor thought were the most important objectives in the course and modeled how those questions might be phrased on tests. They also provided more examples and practice testing which should reduce anxiety in the real test environment. Sixty-seven percent of respondents changed the way they studied or prepared for tests as a result.

- "Seeing more problems beyond the homework and class examples helped prepare me for test questions" (student 3).
- "I used the practices to study for the exam and was helpful to see how you would ask certain questions" (student 6).
- "Helped decide what to study" (student 2)
- "It did help me to see what important things to know and remember were" (student 1).

If retrieval practices help students prepare for tests one would expect test scores to improve when implemented into a course. This trend was not observed in the data, but as stated, this was a small class size with multiple variables changing each year. This gain in testing is better assessed in a controlled setting as was done in the literature cited by Dunlosky et al. Even without the test score for support, student perceptions of retrieval practice were positive.

Students reported that retrieval practice helped them with chapter tests, final exam, and long-term retention. The biggest area of impact was for long-term retention of content which aligns with the goal of teaching. Based on student perceptions, retrieval practice was the most effective of the three evidence-based practices for long-term learning, as well as test and exam preparation. From the instructor's point of view, retrieval practices provide quick feedback to monitor student learning. When students do not do well on certain retrieval practice questions, there is still time for reteaching or additional practice prior to the test. There is also the added benefit of students arriving on time. As these were structured in the course, students were not allowed to make up a retrieval practice if they missed class or arrived late.

Distributed (spaced) practice

In general, spaced practice outperformed students' expectations and served as a useful learning tool with the largest benefit felt in unit test preparation. Students had high expectations for distributed practice with regards to unit test and final exam preparation (average 4.0 and 3.7 respectively). By the end of the semester students confirmed that the practice had helped them prepare for unit tests and the final exam (average 4.3 and 3.9 respectively). The end-of-semester survey did not explicitly ask students to describe their experience with this practice. As such, only one student provided feedback. They wrote, "the spaced-out homework assignments and retrieval practice were very beneficial and proved to be helpful when taking tests" (student 4). No negative comments regarding distributed practice were shared.

Distributed practice can be implemented in several ways. In this class, weekly homework sets and labs were used as an example of a distributed practice. However, the retrieval practice quizzes were also an implementation of distributed practice. The survey question about distributed practice reads, “In this class, spaced practice will be seen by shorter, weekly homework assignments that are due weekly instead of one larger set due at the test.” Students were directed to consider the implementation of spaced homework as an example of distributed practice. Therefore, the survey responses are a critique of spaced homework implementation and not distributed practice in general.

Interleaved practice

Of the three practices, students indicated that interleaving homework was the least helpful for test preparation and long-term learning. At the beginning of the semester, students were least familiar with this practice (average 2.8) but had high expectations for final exam preparation (4.2). However, these expectations were not met through the semester as the average response was only 3.7 for final exam preparation (see Table 4). Additionally, the average with regards to long-term content learning was only 3.3, much lower than the other practices (4.1 and 4.6 for distributed and retrieval practice respectively). Students did not share anything about interleaved practice in the post-semester survey open responses.

At least two reasons may explain the student responses to interleaving that differ from published literature. As with distributed practice, interleaved practice was described to students as practicing old topics alongside new topic in homework, but retrieval practice questions were often pulled from older content and were an example of interleaving. In the survey, students evaluated interleaving as applied in homework and labs, and not interleaving in general. As seen in Table 1, interleaving was only successfully employed for the first half of the semester. Additionally, more questions from topic #1 were interleaved instead of questions from a greater variety of topics. It is uncertain whether this incomplete use of the practice impacted students’ perspectives on the benefits of interleaving.

Conclusion

Throughout the semester, three evidence-based teaching practices were incorporated into a hydraulics course. All three practices aimed to increase student learning through building complex schema for improved recall and long-term memory storage. The employment of three practices in one course blurs distinct benefits from any one practice. Move over, statistical assessment of the success of evidence-based teaching practices was inconclusive when so many variables exist between test subjects and years. Nothing remained constant. However, the student perceptions provided through surveys were valuable as they described how students felt they benefited from the various practices implemented in this course and how they used them to improve learning. Of the three evidence-based teaching practices, retrieval practice, distributed (spaced) practice, and interleaving, students indicated retrieval practice as the most effective. Eighty-nine percent of respondents used retrieval practice quizzes to adjust their study habits and test preparation and 67% thought retrieval practice would help them remember concepts past this course. Many students felt it was important to keep the retrieval practice grade contribution low to minimize stress. Students also reported that distributed practice, as seen through homework sets and labs, outperformed their expectations and was helpful for unit test preparation. According to students, interleaved practice on homework also helped in unit test preparation, but less so than the other practices. Notably, this practice could have been implemented more effectively and consistently throughout the semester. For future study, integrating only one practice per semester would make learning gains associated with the practice more obvious, but more importantly, asking students to comment specifically on each practice would improve the breadth of feedback and perspectives.

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Appendix

Example retrieval practice (daily quizzes)

Retrieval Practice (*)

Name: ____________________

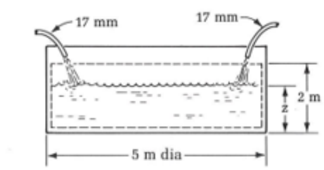
Grade: ______

Questions →

Instructions ↓

1. Put your name on the sheet
2. Closed book/note
3. Answer quickly
4. Include units as needed
5. Self grade
6. Hand in

1. A circular swimming pool 5 m in diameter is being filled with two garden hoses, each having an inside diameter of 17 mm. The velocities of flow from the hoses are 2 m/s and 1.5 m/s. Calculate the time required to fill the pool to a depth of 2 m.



Retrieval Practice (7)

Your partner's name too →

Name: ____________________

Grade: ______

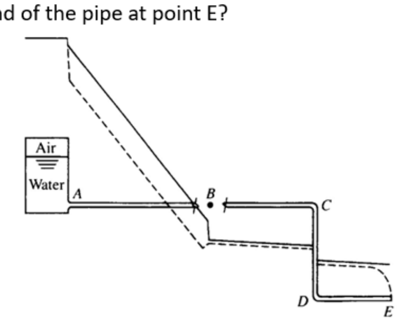
Questions →

Instructions ↓

1. Put your name on the sheet
2. Closed book/note
3. Answer quickly
4. Include units as needed
5. Self grade
6. Hand in

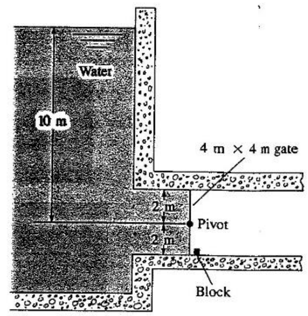
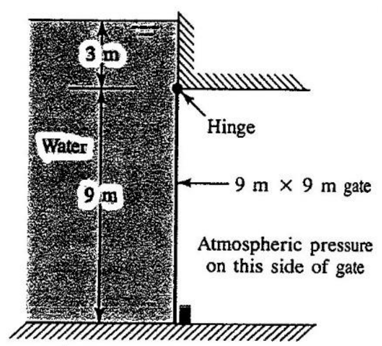
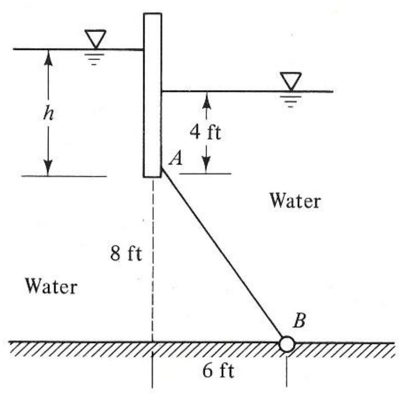
With a partner who doesn't sit in your row

1. Shown here are the HGL and EGL for a pipeline.
   a) Indicate which is the HGL and which is the EGL
   b) Are all the pipes the same size? If not, which is the smallest?
   c) Is there any region in the pipe where the pressure is below atmospheric pressure? If so, where?
   d) Where is the point of maximum pressure in the system?
   e) Where is the point of minimum pressure in the system?
   f) What do you think is located at the end of the pipe at point E?



Example homework assignments

HW2: Hydrostatic Forces

Assigned Problems	Answers
1. A Bourdon gauge reads 100kPa for a column of water. At that pressure, what is the height of the column of a water, if the water is at 10°C, 50°C, and 100°C?	10.2 m (at T=10 °C)
2. Water flows through a pipe of diameter 3 in. If it is desired to use another pipe for the same flow rate such that the velocity head in the second pipe is four times the velocity head in the first pipe, determine the diameter of the pipe.	2.12 in
3. Find the force of the gate on the block. 	104,378 N
4. Neglecting the weight of the gate, determine the force acting on the hinge of the gate. 	2.384 MN
5. Gate AB is 7 ft into the paper and weighs 3000 lb. It is hinged at B and rests against a smooth wall at A. Determine the water level h which will just cause the gate to open. 	4.41 ft
6. Mays (textbook) 3.6.4	4.3 m
7. Mays 3.6.5	1/34

HW10: Risk and Probability

Assigned Problems	Answers
1. A temporary flood wall has been constructed to protect several homes in a flood plain. The wall was built to withstand any discharge up to the 20-year flood magnitude. The wall will be removed at the end of the 3-year period after all the homes have been relocated. Determine the probability for each of the following: a) The wall will be overtopped in any year. b) The wall will not be overtopped during the relocation operation. c) The wall will be overtopped at least once before all the homes are relocated.	a. 5% b. 85.7% c. 14.3%
2. You are to design a highway culvert for a secondary highway. Current practice dictates a 25% acceptable risk that flooding will occur at least once over its 30-year project life. What return period must you use in its design	105 years
3. Do a flood frequency analysis for the Red Cedar River at Lansing Michigan. Use the USGS website (http://waterdata.usgs.gov/nwis/) to get your flow data. Find the 10-, 50-, and 100-year annual peak discharge using three methods: Weibull plotting position method, statistical analysis assuming a normal probability density, and statistical method using a log-Pearson Type III distribution.	Tentative soln: Normal Dist. Q_{10}=3831cfs, Q_{50}=4796 cfs, Q_{100}=5147cfs
4. Water flows into a weigh tank for 30 min. Calculate the increase in the weight of the tank, if the discharge is 1.5 ft^3/s. The temperature is 50^{o}F.	168,663.3 lb
5. Compare the pressure forces exerted on the face of two dams that hold fresh water of 1000 kg/m^3 density and salty water of 1030 kg/m^3. Assume the faces of both dams are vertical.	Pressure force due to salty water is 3% greater than fresh water
6. What is the specific gravity of the salty water in the previous question?	1.03
7. Determine the cross-section of greatest hydraulic efficiency for a trapezoidal channel if the design discharge is 25 ft3/s, the channel slope is 0.00065, and Manning's n = 0.021.	

Example lab activities

Lab 3: Water Distribution Lab

Overview

In pairs (GROUP 3), students will work through several pipe network problems and then solve them using EPANET, Cornell Pump Selection, and Excel.

Objectives:

- Students will increase their understanding of pressurized pipe systems.
- Students will learn how to use software (EPANET) to model and analyze systems.
- Students will learn to select and size a pump for water systems.

Deliverables

Students may respond to questions directly in the Word document provided on Moodle. Model prints (screen clips are OK) and calculations (as needed) may be hand-written, scanned, and inserted into this document. This submission should look like a high-quality homework assignment. <u>Specific printouts required are listed for each part.</u>

Part 1: Learn EPANET by duplicating demonstration

1. Refer to "EPANET" document posted on Moodle that explains background, tools, and provides tips.
2. Determine the flow rate in each pipe for the simple network in Figure 12.6.3 (from *Mays* page 518). Assume fully turbulent flow exists with a roughness of 0.00015 ft (steel) for all pipes.
    a. Before entering the pipe roughness, read what the EPANET manual has to say about roughness (use ctrl+f).

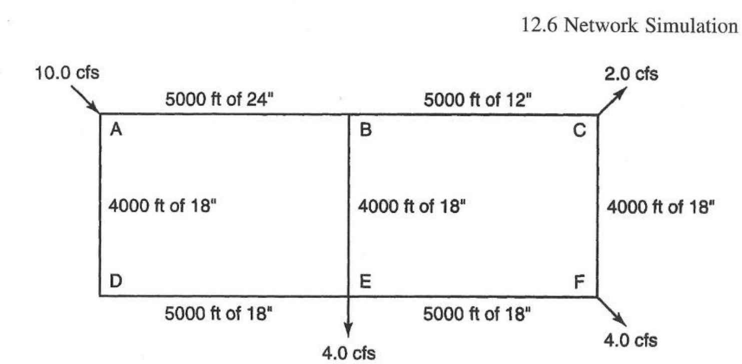


Figure 12.6.3 Pipe network for Example 12.6.1.

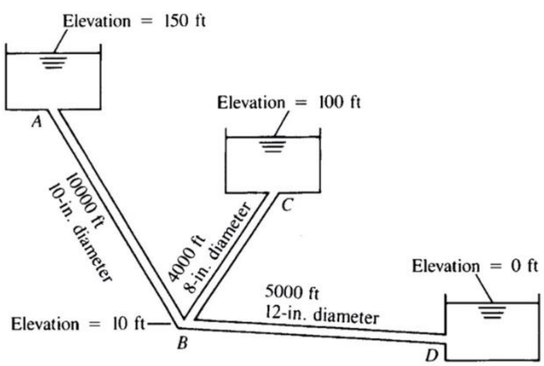
3. Check your work against the textbook (example 12.6.1):

Pipe	Textbook's Discharge [cfs]	JW's EPANET [cfs]
AB	6.3	6.46
BC	2.0	2.36
AD	3.7	3.54
BE	4.3	4.11
CF	0.0	0.36
DE	3.7	3.54
EF	4.0	3.64

4. Review the Hardy Cross Method in Section 12.6.3 in your textbook. (Isn't this similar to what you learned about current/resistance in ENGR 204?)
    a. Do the flows at each node add up to 0? (You can turn on flow arrows in the View/Options menu.)
    b. Do the head losses in each loop add up to 0?
    c. What could account for any discrepancies?
    d. Determine the hydraulic resistance for your pipe AB using the friction factor calculated in EPANET. Using this and the EPANET determined flow rate, verify the headloss through pipe AB. Compare your results to textbook example 12.6.1.
5. **Print out the plan view of the EPANET model showing discharge in pipes and head at the nodes to include with your submission.**
6. **Print out the plan view of the EPANET model showing friction factor (not roughness) in pipes and pressure at the nodes to include with your submission.**

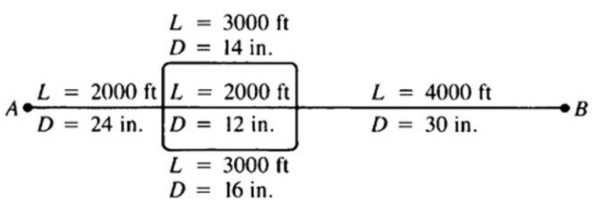
Part 2: Check your homework (from HW4) using EPANET

1. Determine the discharge in each pipe. Neglect minor losses and assume f=0.020. Don't forget to set up your defaults (cfs and DW). Note that you cannot enter in friction factor. You will have to calculate the roughness or "guess and check" until you have f=0.02 for all pipes.
    a. **Print out the plan view of EPANET model showing discharge in pipes and head at the nodes.**



PROBLEM 5-33

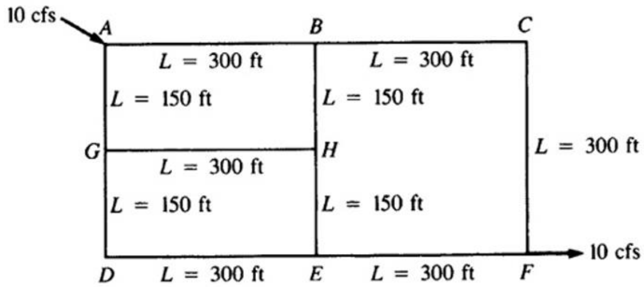
2. Find the headloss and division of flow in each of the pipes from A to B. Assume f=0.030 for all pipes and flow entering point A is 20 cfs.



3.
    a. Is assuming a constant friction factor a good idea? Why or why not?
    b. What material pipe do you think this system uses? Is all of he pipe the same material?
    c. How does your headloss as calculated in your homework compare to the headloss calculated using EPANET?
    d. **Print out the plan view of EPANET model showing discharge in pipes and head at the nodes.**

Part 3: Use EPANET to model a simple pipe network

1. Determine the distribution of flow for the given system using the Hazen-Williams friction formula on EPANET. All pipes are 1-ft diameter galvanized iron. Before you set up your model, go to Project/Defaults/Properties to set the pipe length to 300, auto length to off, pipe diameter to 12, and roughness to 120 (galvanized iron). Model a reservoir at node A to be the source of water.
    a. What is the pressure at point F if the pressure at the source (point A) is 60 psig?
    b. **Print out the plan view of EPANET model showing discharge in pipes and head at the nodes.**
    c. **Print out a second plan view of the EPANET model showing friction factor in the pipes and pressure at the nodes.**



PROBLEM 5-38

Part 4: Select a pump

1. Model the system described in Example 12.5.2 of your textbook using *Pump-student.xlsm* (that you can download from Moodle). Use a pipe roughness of .0003 ft to model the system.
    a. If your desired flow rate is 6 cfs, what is the total head the pump must provide? How did you determine this?
2. Select a Cornell pump operating between 1400-1800 RPM that will provide around 6 cfs in this system at a high efficiency. Double-click on your selected pump to see the pump curve details. On the panel to the right, enter four values for flow (Q) and record the associated head (H). Make sure to include Q=0 (shut-off head). Enter these values in the Flow/Head table. Copy the determined values for C(0) through C(3) and paste those values for one of the pumps listed above on the "Pump Curves" sheet in *Pump-student.xlsm.* Go back to the main page to select that pump and find the match point.
    a. What is the expected efficiency using this pump? (at 6 cfs)
3. **Print the pump curve from Cornell Pumps so that it shows your design point of 6 cfs, your efficiency, and your selected pump model.**
4. **Print the Main page from the *Pump-student.xlsm* that shows your results for the next two parts as well as the solved data using your inputs (including rows 1-40 and columns A-M).**
    a. Show the match point with 1 pump. Print this page.
    b. Show the results of two pumps in parallel. Print this page.

Tables from EPANET manual. (removed for appendix)

Pre-semester survey questions

Question 1: Interleaving involves practicing already-learned material along with newly learned material. In this class it will be seen in homework sets that include questions from earlier in the semester in the current homework set. For example, in chapter 2 on a homework set that includes sections 2.5-2.9, I might include a question from section 2.3 and two from chapter 1. Additionally, links to chapter sections are usually removed.

On a scale from 1 to 5 (with 1 being no previous experience/low expectations and 5 being lots of previous experience/high expectations), please respond to the following:

- How familiar are you with interleaving?
- How well do you expect interleaving to help you prepare for the unit tests?
- How well do you expect interleaving to help you prepare for the final exam?
- How well do you expect interleaving to help you remember concepts past this course?

Question 2: Spaced practice involves spacing out your practice (homework/reading) throughout a unit instead of cramming right before the test. In this class, spaced practice will be seen by shorter, weekly homework assignments that are due weekly instead of one larger set due at the test.

On a scale from 1 to 5 (with 1 being no previous experience/low expectations and 5 being lots of previous experience/high expectations), please respond to the following:

- How familiar are you with spaced practice?
- How well do you expect spaced practice to help you prepare for the unit tests?
- How well do you expect spaced practice to help you prepare for the final exam?
- How well do you expect spaced practice to help you remember concepts past this course?

Question 3: Retrieval practice involves recalling facts, concepts, or events from memory to improve learning. In this class, retrieval practice will be seen as frequent, short quizzes at the beginning of class.

On a scale from 1 to 5 (with 1 being no previous experience/low expectations and 5 being lots of previous experience/high expectations), please respond to the following:

- How familiar are you with retrieval practice?
- How well do you expect retrieval practice to help you prepare for the unit tests?
- How well do you expect retrieval practice to help you prepare for the final exam?
- How well do you expect retrieval practice to help you remember concepts past this course?

Post-semester survey questions

Post-semester survey questions were the same as the pre-semester questions but in past tense. Additional yes/no and free-response questions included:

- Did your grades on the retrieval practices increase your stress and/or anxiety in this class?
- Did your grade or participation in retrieval practices change the way you studied or prepared for the test?
- Please explain how retrieval practice increased your stress/anxiety and/or altered the way you prepared for the test.
- Please share any additional comments you have about this class